I:4
H8

Agricultural and Horticultural Series
General Editor : H. C. Long, I.S.O., B.Sc. (Agric. Edin.)

THE PLANT IN HEALTH AND DISEASE

CENTRAL FOOD TECHNOLOGICAL RESEARCH INSTITUTE,
LIBRARY
* MYSORE. *

1. Secondary Leaf Roll of potato.

2. Sugar beet Virus Yellows (confirmed by transmission test).

3. Tomato leaf with Spotted Wilt.

4. Tulip "Break."

(Photographs by Dr. R. Markham and by permission of Dr. K. M. Smith and the Plant Virus Research Unit, Molteno Institute, Cambridge)

THE PLANT IN HEALTH AND DISEASE

by

W. A. R. DILLON WESTON, M.A., Ph.D., Dip. Agric. (Cantab).
and
R. ERIC TAYLOR, B.Sc.(Agric.), Ph.D.

Formerly Advisory Plant Pathologist and Assistant Advisory Plant Pathologist, School of Agriculture, Cambridge University

Foreword by J. A. SCOTT WATSON,
C.B.E., M.C., B.Sc., M.A.

LONDON
CROSBY LOCKWOOD & SON LTD
39 THURLOE STREET, S.W.7
1948

First Published 1948

TP L 34.

CENTRAL FOOD TECHNOLOGICAL RESEARCH INSTITUTE
LIBRARY
* MYSORE. *

Made and Printed in Great Britain

Foreword

THERE is cause for the gravest anxiety about the food supplies of this country in the coming years, and it is, therefore, the clear duty of every farmer and grower to strive for fuller production.

In the past, food producers have suffered heavy loss—often much greater than they realised—from crop diseases, and from time to time major epidemics have brought widespread famine.

But the science of plant pathology has lately made great strides, and many once-dreaded diseases can now be kept under effective control. Sometimes the solution has been found in the breeding of immune or resistant varieties of the crop plant ; sometimes it has been found in the disinfection of contaminated seed or in the use of fungicidal sprays ; but in other cases success is not to be achieved by these simple and direct measures, and the grower must seek, in better husbandry, the answer to his problem.

This book has been written, by two of my colleagues, out of their long experience in the field, in the course of which they have made several notable discoveries. Their book is a well-balanced account of the subject—emphasising, as it should, the maintenance of plant health rather than the treatment of plant disease. It will be of great assistance to their colleagues—horticulturists as well as agriculturists—in the National Agricultural Advisory Service. But I hope it will also be read and pondered by many actual producers.

J. A. SCOTT WATSON.

Acknowledgments

We are indebted to Mr. W. C. Moore for reading the proofs of this book, and for his helpful criticism. We also wish to thank Mr. F. Hanley, of the School of Agriculture, Cambridge, for reading the chapter relating to nutritional disorders, and Mr. A. J. Flax for his assistance in the preparation of the index. The colour photographs are by Dr. R. Markham, of the Plant Virus Research Unit, Molteno Institute, Cambridge, and the line drawings by Miss A. Murray; it is a pleasure to acknowledge their contributions. On such photographs that are not original, the source is specified, and the authors express their gratitude for permission to reproduce them.

W. A. R. D. W.

R. E. T.

July 15th, 1947.

Contents

		Page
	Foreword	v
	Acknowledgments	vi
	List of Illustrations	ix
Chapter		
I	Plant Disease—Ancient Views and Remedies	1
II	Plant Disease—Modern Views	7
III	The Soil and the Seed	11
IV	The Green Plant and its Environment	18
V	Fungi and Spore Dispersal	28
VI	Classification	38
VII	Symptoms of Disease and Principles of Plant Protection	44
VIII	Seed Treatment—Modern Methods	52
IX	Diseases Caused by Seed-borne Fungi—Cereals	63
X	Diseases Caused by Seed-borne Fungi—Other Farm Crops	69
XI	Soil " Sickness "	77
XII	Soil-inhabiting Fungi that cause Disease	84
XIII	Some Tomato Diseases	93
XIV	Diseases Spread by Air-borne Spores	106
XV	Nutritional Disorders	120
XVI	Virus Diseases	129
XVII	Legislation	141
XVIII	Technical Advice	149
	Appendix I Classified List of Diseases	153
	II List of Useful References	164
	Index	165

List of Illustrations

Frontispiece.—1. Secondary Leaf Roll of potato. 2. Sugar beet Virus Yellows. 3. Tomato leaf with Spotted Wilt. 4. Tulip "Break"

Plate I.—1. A glass model of the Potato Blight fungus *Phytophthora infestans*. 2. Photomicrograph of the sucking parts of an aphis penetrating the tissue of a leaf . . . . . *facing p.* 12

Plate II.—1. Crystals of Tomato Bushy Stunt virus greatly enlarged. 2. Carrot attacked by Broom Rape (*Orobanche* sp.). *between* 12/13

Plate III.—1. Wheat ears showing frost injury. 2. Field bean—frost injury followed by the Chocolate Spot disease (*Botrytis* sp.) *between* 12/13

Plate IV.—1. The effect of chalk on sugar beet growing on acid land in East Suffolk. 2. The effect of chalk on sugar beet growing in a light, acid soil at Tunstall, Suffolk . . . . . *facing p.* 13

Plate V.—Photomicrographs of weed seeds scheduled in the Seeds Act, 1920: (a) *Rumex acetosella*; (b) *Rumex crispus*; (c) *Bromus mollis*; (d) *Holcus lanatus*; (e) *Daucus carota*; (f) *Geranium dissectum*; (g) *Geranium molle* . . . . . *facing p.* 20

Plate VI.—Crown Gall of sugar beet (*Bacterium tumefaciens*) *facing p.* 21

Plate VII.—The Clover Rot Fungus growing on synthetic medium: (a) in a petri dish; (b) in glass tubes plugged with cotton wool *facing p.* 28

Plate VIII.—Models of the summer and winter stages of a species of *Erysiphe* greatly enlarged: (a) summer stage; (b) winter stage . . . . . *between* 28/29

Plate IX.—1. Apples covered with pustules of the Brown Rot fungus *Sclerotinia fructigena*. 2. Spores of *Sclerotinia fructigena* on a wasp's leg . . . . . *between* 28/29

Plate X.—1. Scab lesions produced on apples by the fungus *Venturia inaequalis*. 2. Photomicrograph of *Penicillium notatum* *facing p.* 29

Plate XI.—1. Conidia of *Venturia inaequalis* on a leg of an aphis. 2. Ears of rye, barley and wheat attacked by Ergot (*Claviceps purpurea*) . . . . . *facing p.* 36

Plate XII.—1. A splash in a liquid—photographed by means of the "Kodatron Speed Lamp." 2. Model of a pycnidium liberating spores (greatly enlarged). 3. Splash pattern produced by a drop of milk falling on a milk film . . . . . *between* 36/37

Plate XIII.—1. Leaf Spot of sugar beet caused by *Cercospora beticola*. 2. A glass model of a species of *Cercospora* greatly enlarged *between* 36/37

Plate XIV.—Black Scurf and Stem Canker of potato (*Corticium Solani*): (a) The mycelial stage (*Rhizoctonia*) on the tuber; (b) The perfect stage (*Corticium*) on the stem . . *facing p.* 37

Plate XV.—Powdery Scab of potato (*Spongospora subterranea*): (a) Symptoms on the tuber; (b) Photomicrograph of the "spore balls" in a section through infected tissue . . . *facing p.* 44

Plate XVI.—A glass model of the basidia and basidiospores of one of the larger *Basidiomycetes*. . . . . *between* 44/45

Plate XVII.—1. A badly laid crop of oats near Margaretting, Essex. 2. Lodging in a wheat crop in Norfolk due to the Eyespot fungus (*Cercosporella herpotrichoides*) . . . . . *between* 44/45

Plate XVIII.—The Fire disease of tulip (*Botrytis Tulipae*): (a) Primary infection; (b) Blemishes produced on a tulip flower by secondary infections . . . . . *facing p.* 45

Plate XIX.—1. A power-driven machine acquired by the Cambridge University Farm in 1925, for disinfecting seed wheat. 2. A modern type of continuous-feed, power-driven machine *facing p.* 52

Plate XX.—1. Machinery installed for disinfecting seed corn at the National Institute of Agricultural Botany. 2. Disinfecting corn on the barn floor . . . . . *between* 52/53

Plate XXI.—A simple machine for disinfecting small quantities of grain . . . . . *between* 52/53

Plate XXII.—1. Abnormal germination of cereal seed. 2. Leaf Stripe of barley (*Pyrenophora graminea*=*Helminthosporium gramineum*). 3. Leaf Blotch of barley (*Rhynchosporium Secalis*) . . . . . *facing p.* 53

Plate XXIII.—Bunt of wheat (*Tilletia caries*): (a) Infected ear; (b) Grain contaminated with spores; (c) Bunt balls; (d) Photomicrograph of Bunt spores . . . . . *facing p.* 60

Plate XXIV.—1. Ears of wheat infected with Loose Smut (*Ustilago Tritici*). 2. Oat Smuts (*Ustilago* spp.) . . . . *between* 60/61

Plate XXV.—1. Covered Smut of barley (*Ustilago Hordei*). 2. Photomicrographs of the spores of: (a) *U. Hordei*; (b) *U. nuda*. 3. Loose Smut of barley (*Ustilago nuda*) . . . . *between* 60/61

Plate XXVI.—Leaf Stripe of barley (*Pyrenophora graminea*=*Helminthosporium gramineum*): (a) Seedling symptoms; (b) Symptoms on the mature leaf . . . . . *facing p.* 61

Plate XXVII.—Leaf Spot and Seedling Blight of oats (*Pyrenophora Avenae*=*Helminthosporium Avenae*): (a) Infected seedlings; (b) Photomicrograph of spores . . . . . *facing p.* 68

Plate XXVIII.—The effect of treating seed oats with an organo-mercury dust on a farm in Cardiganshire . . *between* 68/69

Plate XXIX.—Stripe Smut of rye (*Urocystis occulta*): (a) Infected tillers; (b) Photomicrograph of spores . . . . *between* 68/69

Plate XXX.—Peas plated out on a nutrient medium in petri dishes: (a) Untreated seed; (b) Seed previously treated with an organo-mercury seed disinfectant . . . . . *between* 68/69

Plate XXXI.—1. Black Leg of sugar beet (*Phoma Betae*). 2. Sugar beet seedlings attacked by the Pigmy Mangold Beetle (*Atomaria linearis*) . . . . . *between* 68/69

Plate XXXII.—Celery Leaf Spot (*Septoria Apii-graveolentis*): (a) Seedling infection; (b) Symptoms on an older leaf *facing p.* 69

Plate XXXIII.—Celery Leaf Spot (*Septoria Apii-graveolentis*): (c) A leaf petiole (enlarged) covered with pycnidia; (d) Photomicrograph of a section through a pycnidium . . *facing p.* 76

Plate XXXIV.—Take-All and Whiteheads of wheat (*Ophiobolus graminis*): (a) Wheat seedling—the roots attacked by runner hyphae; (b) Photomicrograph of runner hyphae; (c) Affected plant with diseased roots, and base blackened with plate mycelium; (d) Blind ear (whitehead) discoloured by saprophytic moulds; (e) Photomicrograph of plate mycelium on stem base; (f) Photomicrograph of immature perithecia *between* 76/77

Plate XXXV.—Violet Root Rot (*Helicobasidium purpureum*): (a) On sugar beet; (b) On carrot . . . . . *between* 76/77

Plate XXXVI.—Clover Rot (*Sclerotinia Trifoliorum*): (a) Dead clover plant with sclerotia; (b) Apothecia growing from sclerotia in clover débris; (c) Apothecia growing from sclerotia in the soil . . . . . *facing p.* 77

Plate XXXVII.—Sclerotinia Disease of bean—Bean Rot (*Sclerotinia Trifoliorum*): (a) Diseased bean plant in a field crop; (b) Bean stalk cut lengthwise to show sclerotia . . . *facing p.* 84

Plate XXXVIII.—1. Beet "sickness"—a patch of stunted plants infested with eelworm (*Heterodera Schachtii*). 2. Sugar beet with roots infested with eelworm cysts . . . *between* 84/85

Plate XXXIX.—Potato root eelworm (*Heterodera rostochiensis*): (a) Field symptoms of potato "sickness"; (b) Eelworm cysts on a root (enlarged) . . . . . *between* 84/85

Plate XL.—Club Root of cabbage (*Plasmodiophora Brassicae*): (a) Diseased root; (b) Photomicrograph of a section through diseased tissue . . . . . *facing p.* 85

Plate XLI.—Wart Disease of potato (*Synchytrium endobioticum*): (a) Potato stem with tumerous growth at soil level; (b) Photomicrograph of a section through diseased tissue . *facing p.* 92

Plate XLII.—Dry Rot of potato (*Fusarium caeruleum*): (a) Symptoms on the tuber; (b) Photomicrograph of the spores showing chlamydospores . . . . . *between* 92/93

Plate XLIII.—Root of a gooseberry bush enlaced with the rhizomorphs of the Honey Agaric (*Armillaria mellea*) . *between* 92/93

Plate XLIV.—1. Verticillium Wilt or Sleepy Disease of tomato (*Verticillium albo-atrum*)—the conidial stage of the fungus. 2. Stem and Fruit Rot of tomato (*Didymella Lycopersici*): (a) A severely affected stem of a mature plant . *facing p.* 93

Plate XLV.—Stem and Fruit Rot of tomato (Didymella Lycopersici): (b) A diseased fruit; (c) Photomicrograph of the pycnidia *facing p.* 100

Plate XLVI.—1. Tomato fruit with spotting caused by the Grey Mould fungus (*Botrytis cinerea*). 2. A glass model of the Grey Mould fungus, greatly enlarged . . . . . *between* 100/1

Plate XLVII.—1. Tomato fruits affected with the Potato Blight fungus (*Phytophthora infestans*). 2. Dry Set—a physiological disorder . . . . . *between* 100/1

Plate XLVIII.—Black Rust of wheat (*Puccinia graminis*) . *facing p.* 101

Plate XLIX.—Black Rust of wheat (*Puccinia graminis*): (a) Photomicrograph of uredospore pustules on wheat; (b) Photomicrograph of germinating uredospores . . . . . *facing p.* 108

Plate L.—(c) Photomicrograph of teleutospores; (d) Photomicrograph of a section through a spermagonium . . *between* 108/9

Plate LI.—(e) Photomicrograph of a section through a barberry leaf with a young aecidium on the lower surface, and spermagonia on the upper; (f) Photomicrograph of a cluster of aecidia *between* 108/9

Plate LII.—1. Aeroplane dusting a crop of wheat in the Prairie Provinces of Canada. 2. American Gooseberry Mildew (*Sphaerotheca mors-uvae*) . . . . . *facing p.* 109

Plate LIII.—1. Potato Blight. 2. Photomicrograph of the Potato Blight fungus (*Phytophthora infestans*) . . . *facing p.* 116

Plate LIV.—1. Section through a potato tuber infected with Blight. 2. Spraying a potato crop with a tractor-drawn spraying machine. 3. Applying a fungicidal dust to a Fenland potato crop . . . . . *between* 116/17

Plate LV.—Clearing and cultivating the site of an old potato clamp *between* 116/17

Plate LVI.—1. Downy Mildew of sugar beet (*Peronospora Schachtii*). 2. A glass model of a species of *Peronospora* . . *facing p.* 117

Plate LVII.—1. Speckled Yellows of sugar beet. 2. Early stages in Heart and Dry Rot of sugar beet . . . . . *facing p.* 140

Plate LVIII.—Examining seed samples in the Official Seed Testing Station, Cambridge . . . . . *between* 140/1

Plate LIX.—Map of England and Wales showing the eight Advisory Provinces . . . . . *between* 140/1

Plate LX.—The National Institute of Agricultural Botany, Cambridge . . . . . *facing p.* 141

The glass models of fungi illustrated are the work of the senior author

Description of Text Figures

Fig. *Page*

1. An Official Seed Testing Station report 17
2. Diagram of a bean root with nodules containing the nitrogen-fixing organism *Rhizobium leguminosarum* 24
3. The mark of an approved product 57
4. Young tomato plants affected with Foot Rot 94
5. A tomato plant with Black Dot disease—Root Rot (*Colletotrichum atramentarium*). Inset—roots with minute sclerotia . 97
6. Verticillium Wilt or Sleepy Disease of tomato (*Verticillium albo-atrum*). A diseased plant with stem split lengthwise . . 99

Chapter One

Plant Disease—Ancient Views and Remedies

From the earliest times farmers have striven to prevent disease, for on the outcome of the harvest famine or plenty have always depended. In olden days when crops withered mysteriously they were said to be blasted or blighted, and these terms were used to cover a wide range of diseased conditions. Before the causes of disease in plants were understood many different reasons were advanced to account for it. The weather was often blamed, especially the East Wind, " . . . and I saw in my dream, and behold, seven ears came up upon one stalk, full and good : and behold, seven ears, withered, thin, and blasted with the East Wind, sprung up after them . . ." * Disease was also attributed to the displeasure of the Gods, and to avert their wrath sacrifices or peace offerings were made. For example, the ancient Romans sacrificed a red dog to Robigus, the Corn God, for they thought there was some connection between the dog star and epidemics of a rusty-red blight that often appeared on the growing corn. The ancient Greeks made supplications to the Corn Goddess that evil might be averted and, when the harvest was safely gathered in, paid tribute to Demeter with thank-offerings of grain.

In the Middle Ages the blasting of crops, the apparently spontaneous generation of noxious insects, and many other happenings were often ascribed to witches. In Lorraine in the sixteenth century, in a short period of fifteen years, 900 people paid the penalty of death for witchcraft.

From ancient days until as recently as the nineteenth century the sowing of the seed was attended with much ceremony. To propitiate the Corn Spirits, which were believed to control productivity, various religious, superstitious and magical rites were practised. Not all these are as pleasant to contemplate as the votive offerings of the ancient Greeks. Animals and human beings were often immolated on the altars of sacrifice,

*Gen. xli, 15-23.

and their blood or ashes scattered over the fields or mixed with the seed corn. In his epic study of magic and religion Fraser* notes that the ancient Mexicans sacrificed human beings at all stages in the growth of maize. The age of the victims corresponded to the age of the corn, for, he writes, " they sacrificed new-born babes at sowing, older children when the grain had sprouted, and so on till it was fully ripe, when they sacrificed old men." He adds, laconically, " No doubt the correspondence between the ages of the victims and the state of the corn was supposed to enhance the efficacy of the sacrifice."

It is not necessary here to examine the complexity of the many superstitious rites that were practised to threaten or appease the Corn Spirits, and for further information the reader is referred to *The Golden Bough*. He should note, however, that even to-day traditional forms of many of these rites are practised, and that, although in most instances the significance of such customs has long since been forgotten, their practice serves to preserve from extinction the folk-lore of many countries. " But," says Jethro Tull,† " unless these peasants had been better engineers than the giants, in besieging heaven, their menaces must be vain."

In time different forms of blasting or blighting were recognised, and more specific terms were then used to describe them. These were usually based on some striking symptom or appearance of the disease. The names were not standardised, as they are now, but varied from place to place. On wheat the disease that turned the green corn rusty-red in colour was known as Rust or Red Robin, and another that destroyed the grains, filling them with a dusty, evil-smelling, brownish-black powder, as Smut.

It must not be thought that religious and superstitious rites were the only means adopted to prevent plant disease. The Gods may be infallible, but there are always some mortals who prefer to base their judgment on observation and experiment rather than accept assumptive evidence. This inquiring purpose is the criterion of the scientific mind : it is

*Fraser, J. G. (1933). *The Golden Bough*, Vol. 1, Part V. Spirits of the Corn and the Wild, p. 238.

†Tull, J. (1733). *The Horse-Hoing Husbandry*, p. 68.

not the product of a modern age, but is as old as man himself. There is circumstantial evidence that the prevention of some diseases was obtained centuries ago. An example is the ingenuity shown in devising "steeps" for the treatment of seed corn. How did it come about? Centuries before the causal agents of decay were known, methods had been devised to retard its progress. Embalming was a highly-developed craft, and, by the application of balsams and spices, putrefaction could be arrested for very long periods. Might it not be possible to use this principle, or similar ones, to protect the living seed in the soil and to prevent its decay? Who can say how the thought first arose and by whom it was first practised? Pliny, a prodigious compiler of natural history notes, has recorded that seed was sometimes steeped in wine, urine, or certain vegetable juices.

It would seem, therefore, that seed treatment is not a novel device of modern science, but an ancient practice that was eclipsed for a time when the light of ancient Greek and Roman civilisation faded. It was revived again, however, and from the sixteenth century onwards there are many references to it. Numerous concoctions were prepared for steeping grain and various materials were used. These included alum, animal offal, arsenic, beef-broth, claret, copper sulphate, dung, garlic, gypsum, lime-water, plant ashes, salt, soot, sulphur, certain vegetable powders and urine. Many of the steeps contained numerous ingredients and various methods were devised to treat the grain.

For example, Speed,* writing in 1659, suggested that persons having much land should be provided with a "moat or standing pool" wherein might be thrown all manner of farm manure, especially rabbit dung, together with such oil, ale, perry, cider, beef-broth, etc., as could be spared, and also blood, urine and other waste. In addition to watering the land with this potent fluid by means of an engine "in part like that they use in London, when houses are on fire," Speed steeped corn in it for twenty-four hours and stated that one might expect better fertility and profit.

In *Winter Riches*, published in 1771, Matthew Peters records that a Monsieur Donat near Rochelle used the follow-

*Speed, A. (1659). *Adam out of Eden*, pp. 121-128.

ing preparation :—" Twenty-five pounds each of quick-lime and pigeon's dung, 40 pounds of wood ashes, and 25 pounds of sea-salt or saltpetre. This was sufficient to prepare 12-13 cwt. of wheat." It seems that this preparation prevented smut, for in seven years Monsieur Donat never had a smutted ear.

It is interesting to note that even in those days some of the preparations used were proprietary articles and were named after the maker, e.g., Pluche's Preparation, and Bronguiart's Vegetable Powder. Further, as is done to-day, contracts were made to treat a farmer's seed corn. " A sort of chymist came down to these parts some years ago, to teach us a dressing for corn, by way of brining ; which, applied to wheat or barley, would, he said, make the poorest ground bear a crop continually, and so rank, as that a peck of wheat less per bushel would sow an acre."*

Brining seed wheat to prevent smut was not a novelty even then, for Tull† remarks, " Brining of wheat, to cure or prevent smuttiness (as I have been credibly informed) was accidentally discovered about seventy years ago, in the following manner, viz. : A ship-load of wheat was sunk near Bristol in autumn, and afterwards at ebbs all taken up, after it had been soaked in sea water ; but it being unfit for making of bread, a farmer sowed some of it in a field, and when it was found to grow very well, the whole cargo was bought at a low price by many farmers, and all of it sown in different places. At the following harvest, all the wheat in England happened to be smutty, except the produce of this brined seed, and this was all clean from smuttiness. This accident has been sufficient to justify the practice of brining ever since in all the adjacent parts, and in most places in England. . . ."

Then, as now, sweeping claims were often made for various recipes and cures for plant disease. It is impossible to assess the value of these old recipes, for distinction was seldom made between the different sorts of smut, but it is most probable that successful control of some kinds was obtained long before the cause was known. Apart from any question of preventing

*Bradley, R. (1724). *A General Treatise of Husbandry and Gardening*, Vol. 3, pp. 77-78.

†Tull, J. (1733). *The Horse-Hoing Husbandry*, pp. 66-67.

disease, it seems that seed treatment before sowing was also done in the belief that a stimulatory effect resulted. With some of the " steeps " then employed it is possible that this may have occurred, for, in recent years, certain chemicals that have a marked effect in promoting growth responses have been discovered, and some of these growth-promoting substances or " hormones " are present in natural manures.

Although steeping seed corn may have prevented Smut, it was of no value in curing Rust, but, here again, some measure of control was discovered many years before the cause of the disease was fully appreciated. It had been noticed that Rust was often more severe in the neighbourhood of barberry bushes. Was there any complex relationship between the two? Would it be possible to prevent Rust by destroying the barberry? Circumstantial evidence that this course might be justified was so strong that in some countries laws were made that this should be done. Indeed, as early as 1756, this was enforced by legislation in Massachusetts. The cause and the prevention of Rust is one of the fascinating stories in the romantic history of plant disease, but to appreciate the pioneer work that was necessary before the problem was finally solved, the reader is referred to *The Advance of the Fungi*,* which traces the history of plant disease (and the trials and triumphs of plant doctors) from ancient to modern days.

Smut and Rust were not the only diseases that plagued corn crops in olden days. A peculiar malady affected rye. Instead of healthy grains developing, hard, horn-shaped, purple-coloured " kernels " were formed. The cause of these bodies, or ergots as they are now called, was unknown. Some believed that they were due to the rye flowers not having been fertilized, while others thought that excessive humidity of the air or the bite of an insect was responsible. In the Middle Ages it was not realised that " Ergot's horn uncouth " contained a dangerous poison. When grain containing ergots was ground for flour and used for bread, poisoning resulted. Violent burning pains consumed the body, especially the hands and feet, which became inflamed and swollen. If

*Large, E. C. (1940). *The Advance of the Fungi.* 488 pp. London : Jonathan Cape.

recovery did not take place the affected parts became gangrenous and dropped off. This terrifying disease was called " holy fire " and came to be associated with St. Anthony and St. Martial.

Barger* states : " A plague of ' fire ' is first mentioned in 945, in and around Paris. Limbs were burnt up and gradually consumed, until death ended the torment. As many as could reach the Church of St. Mary in Paris were saved, and Duke Hugh fed them with daily rations. When some of the patients went home, the quenched fire was rekindled, but returning to the Church they again recovered." " Evidently," as Barger says, " he had a store of sound grain, and relapses occurred when the patients fell back on their own supplies." It was not until the eighteenth century, however, that " holy fire " was identified as gangrenous ergotism, and ergots were suspected to be fungus bodies. This fungus is now known as *Claviceps purpurea*, and it is a prevalent disease of rye in many countries, but cases of ergot poisoning are now rare, as precautions are taken to remove the ergots from grain samples.

Although the Rust and Smut diseases had been known from time immemorial, it was not until the discovery of the microscope in the seventeenth century that scientists were provided with the means of determining the cause. Kircher, in 1659, and Van Leeuwenhoek, in 1675, saw and described minute living organisms that their microscopes revealed, but many years passed before these and other microbes were proved to be the agents of putrefaction, fermentation and disease. In 1752 Mathieu Tillet proved the infective nature of the black dust-like powder in smutted ears of wheat. Later, in 1807, Bénédict Prévost showed that this dust consisted of the spores of a minute fungus. The nature of disease was soon to be revealed ; the stage was set, and the curtain ready to be drawn aside.

*Barger, G. (1931). *Ergot and Ergotism*, pp. 43-44. London and Edinburgh : Gurney and Jackson.

Chapter Two

Plant Disease—Modern Views

As seen under the microscope the actors in the strange dramas that were to be unfolded were minute plants—bacteria and fungi. These were the malign spirits of the Gods, the Devil and the " evil eye." Long intervals often elapsed, of course, between the more important discoveries, which, as might be expected, provoked much controversy. This was so in 1845 when the potato crops on the Continent and the British Isles were suddenly affected with a disease that spread with alarming rapidity. Not only was the haulm killed, but the tubers rotted and disastrous failures resulted. This plague, which was then called the potato murrain, was the disease now known as Potato Blight. In Ireland the loss of the potato crop led to famine, and in the tragic years 1845-47 tens of thousands of men, women and children died of starvation.

What was the cause of this hitherto unheard-of putrescence ? Could it be due to a fungus, a mould growth that had been observed on the decaying haulm ? Most botanists thought not, because it was considered that such organisms were the result of disease and not the cause of it. This attitude was understandable, because at that time many naturalists still believed in spontaneous generation—the creation of life from the decomposing remains of plant and animal matter. The theory was sanctified by tradition and was based on the previous conceptions of the great naturalists of antiquity. The Rev. M. J. Berkeley, a celebrated English botanist, did not hold this view, however, for by his detailed observations he had come to the conclusion that the fungus on the decaying potato haulm was the cause of the murrain and not the result of it. This, indeed, was true, and the subsequent researches of others confirmed his opinion that the mould, which we now know as *Phytophthora infestans*, was the causal agent of Potato Blight.

A botanist had blazed the trail, but it was the brilliant

insight of Louis Pasteur (1822-95), chemist, physician and bacteriologist, who drove the road through the jungle of hypotheses, paved it with scientifically proved principles, and established the highway for the conquest of disease. Spontaneous generation was proved a myth, and fermentation and putrefaction were shown to be the result of natural causes, the activities of micro-organisms. The layman referred to these as germs or microbes, but the scientist saw them as minute plants, bacteria and microscopic fungi. Stimulated by the exact and delicate researches of Pasteur, the germ theory of disease came into being. Forever linked with the name of this immortal Frenchman is his great contemporary, the beloved surgeon Lister (1827-1912), who applied the principles which Pasteur had discovered to the alleviation of human suffering.

Did germs cause wounds to suppurate and become gangrenous, and so lead to the mortality attendant on any serious surgical operation? If so, could infection be avoided by scrupulous cleanliness in hospital and surgery? Further, if germs were the cause of septic conditions—and Lister was convinced that they were—would it be possible to counter their activities by treating the wounds with antiseptics, chemicals that would kill or inactivate the germs before they had a chance to cause putrefaction? Observations and experiments proved that this was possible. Listerian practice followed Pasteurian principle, and prophylactic methods and the use of antiseptics gave a new hope to mankind.

During the last quarter of the nineteenth century many brilliant discoveries were made relating to disease. Robert Koch, besides demonstrating the organisms that cause anthrax and tuberculosis, placed the study of bacteria on a secure foundation by devising standard methods whereby they could be grown in artificial culture and studied under laboratory conditions. Two new sciences came into being, the study of bacteria—bacteriology, and the study of fungi—mycology. The germ theory of disease was securely established, and the way was clear to the conquest of many diseases that plagued mankind, his cattle and his crops.

We have read, however, "... the earth's a thief, that feeds and breeds by a composture stolen from general excre-

ment."* As we shall see later, many micro-organisms are beneficial, for, by decomposing dead plant and animal matter, they release plant foods so that life may bloom anew.

Are there no other causal agents of disease, besides parasitic fungi and bacteria? In 1892, Ivanowski found that the sap of diseased tobacco plants showing a peculiar mosaic appearance was infectious to healthy plants. Indeed, it was still infectious after it was passed through a filter which held back bacteria and other known micro-organisms. Later, other diseases of a somewhat similar nature were discovered, and it was shown that this kind of ailment was not due to microscopic fungi or bacteria, but to some " infection principle " or, as we now say, to a virus. To-day many such maladies are known, and there seems to be no limit to their diversity, for they plague almost every form of life. Man is affected with yellow fever, typhus, mumps, smallpox and measles, cattle suffer from foot-and-mouth disease, and potatoes from Leaf Roll and Mosaic.

What are the properties of viruses? They are able to multiply in a living cell but not outside it, and they are so extremely small (they pass through the pores of a filter that will restrain microscopically visible bacteria) that they cannot be seen with the aid of the ordinary microscope. Many virus diseases, of which more than a hundred are known, are transmitted by insects. For example, the " carrier " of Leaf Roll, or the *vector* as it is called, is the aphis *Myzus persicae.* When this greenfly feeds on an infected plant it sucks up some of the virus and later injects it into healthy plants on which it feeds. Are viruses endowed with life, or are they inanimate particles of matter capable of being regenerated within the body of a living cell? " In any event, we are face to face with the ' infinitely small in biology,' and if there be a sharp demarcation between life and death, then scientists, investigating the nature of viruses, are working near the line that separates infinitely small living organisms from inanimate active agents."†

In 1935 much light was thrown on the nature of viruses by Stanley's experiments in America. He succeeded in isolating,

*Timon of Athens, Act IV, Sc. 3.

†Rivers, T. M. (1932). The Nature of Viruses, *Physiol. Rev.*, **12**, pp. 423-452.

from tobacco plants affected with a virus disease known as Mosaic, a substance which he claimed to be " a crystalline material, which has the properties of tobacco-mosaic virus." Later, however, it was necessary to modify these findings, for Bawden and Pirie, in their pioneer work on the purification of viruses, showed that this particular virus was not truly crystalline. Shortly afterwards they succeeded in isolating and purifying a virus in a true crystalline state—the virus causing Bushy Stunt of tomato. It is not within the scope of this book, however, to detail the intricacy of these studies or to forecast the trend of future research.

Although the main causes of plant diseases are parasitic fungi, bacteria and viruses, crop failures arise in many other ways. The land may be in poor heart and the level of fertility low, the soil sour or badly drained. The seed may be of poor quality and the germination capacity low, or the variety ill-adapted to the soil type. Weeds may strangle the crop, or certain parasitic flowering plants injure it. Frost, hail, excessive rain or drought may intervene, and insect pests, birds and vermin take their toll.

The Gods, benign or malevolent, the capricious spirits of the corn and of the wild, the " evil eye " : these were the old philosophies nurturing superstitious fears and tricking men into false beliefs. It is not so to-day. The ravages caused by micro-organisms are not plagues to be endured but to be prevented. Before the activities of these parasites are dealt with in more detail, however, the seed and the green plant should be considered in relationship to their environment.

Chapter Three

The Soil and the Seed

Stored within the seed, ready for its awakening, is the embryo's larder—foodstuffs consisting of carbohydrates, fatty oils and proteins. As might be expected, the various sorts of seeds store up different quantities of these materials; thus peas and beans are rich in protein, mustard in vegetable oils, and the cereals in carbohydrates. It is from these food reserves that energy will be drawn when germination starts. The conditions necessary before this can take place are moisture, air, and a suitable temperature. In the soil, warmed by the sun, the seed absorbs moisture, life stirs within it, respiration increases, and ferments change the insoluble foods into soluble form.

This is a most critical period in the life of the young seedling, for if germination is unduly delayed, as may happen when adverse weather conditions prevail, the food reserves may become exhausted before the developing plant can fend for itself, and a high mortality may result. In addition, if the young seedling is unable to " grow away " quickly, it is more likely to succumb to harmful organisms present in the soil or borne on the seed coat. As we shall see later, it is sometimes possible to guard against this eventuality by treating the seed before sowing with a fungicidal powder or liquid.

At this early stage the relative fertility of the soil is unimportant compared with the plant's food reserves, but the time comes when they are exhausted and the seedling must obtain its own supplies, putting forth its first leaves to the sun, and sending its roots to explore the charity or the bounty of the soil.

In the natural state seeds are dispersed in many ways, and it is largely a matter of chance where they come to rest. " . . . Some fell upon stony places, where they had not much earth : and forthwith they sprung up, because they had no deepness of earth : and when the sun was up, they were scorched ; and because they had no root, they withered away.

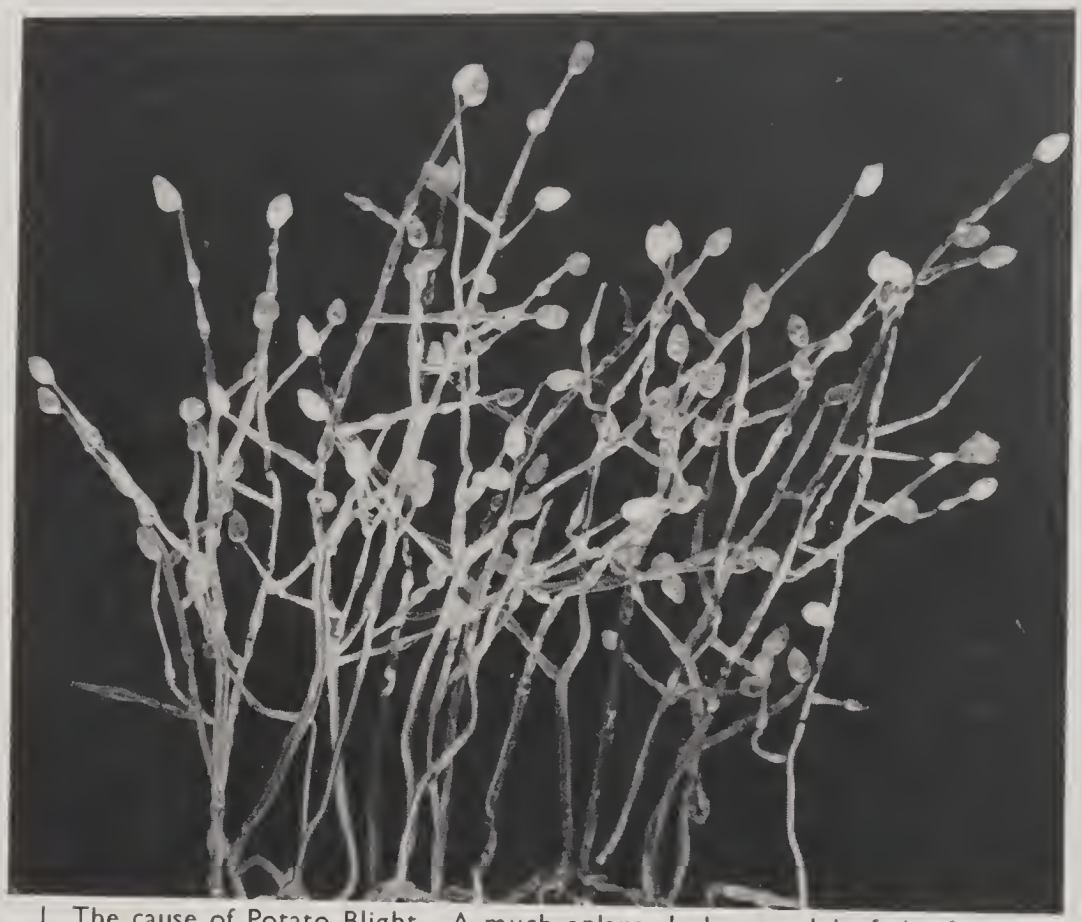
And some fell among thorns ; and the thorns sprung up, and choked them : but others fell into good ground, and brought forth fruit, some an hundred fold, some sixty fold, some thirty fold."*

The earth is carpeted with various patterns of plant life and there are few soil types or climates where plants cannot be found. Rocky mountain-sides, fertile valleys, the jungle, the desert and the marsh ; chalky and " sour " soil ; clay, silt, loam, sand—each has its own type. In the countless ages since the crust of the earth first formed and soil came into being, plant life has slowly evolved, producing types able to survive in the most diverse conditions of climate and of soil. The natural historians of earlier times thought that all the various forms of life were fixed and unchangeable, but it is now known that the adaptation of plants to their environment has been brought about by modifications in the structure and functions of their tissues. Lamarck, in 1801, accounted for these changes by assuming that characteristics developed or acquired by the plant in the course of its life could be transmitted to the seed ; this view, the inheritance of acquired characters, is now discredited. Darwin, in *The Origin of Species*, 1859, considered that all living organisms had evolved from simpler forms of life and that by a very gradual process of natural selection only those well adapted to their environment survived. De Vries, in the *Mutation Theory*, published in 1900, suggested that the effective changes, or variations, occurred not by slow degrees, but by sudden alterations—the appearance of mutations or sports. Modern botanists interested in the science of genetics (the study of heredity and variation) believe this to be the most likely explanation, and they are now attempting to discover the causes that lead to these sudden changes.

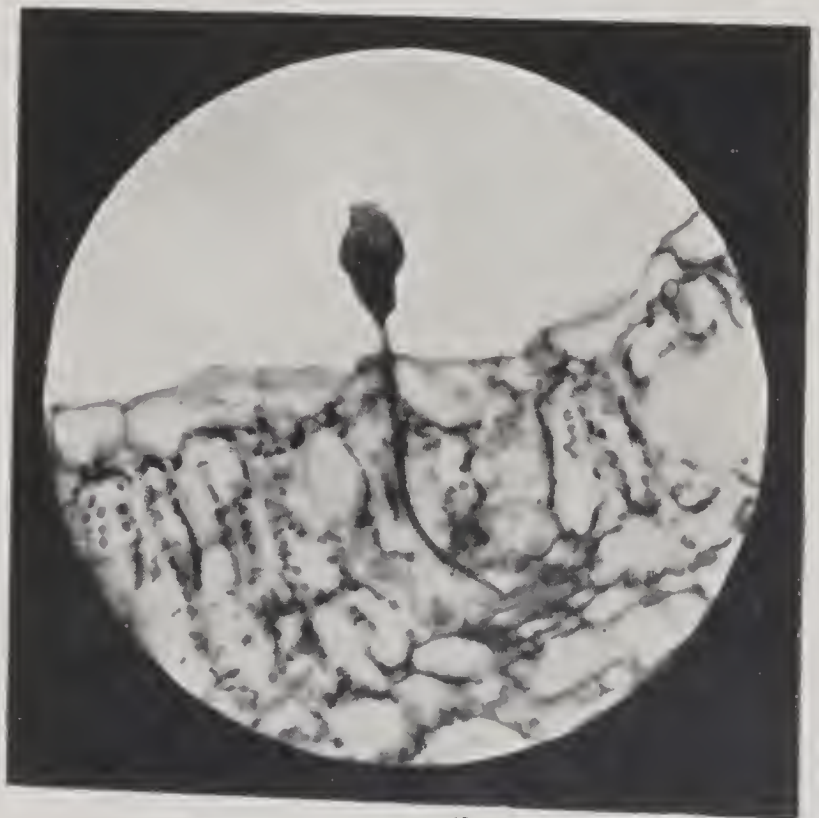
The laws of heredity on which the science of genetics and plant breeding is based were discovered many years ago by Gregor Mendel, an Augustinian monk, Abbot of a monastery at Brünn, Austria. His observations were published in a scientific paper in 1866 but attracted little attention at the time from his scientific colleagues. Thirty-four years later his work was rediscovered independently by the three botanists,

* Matt. xiii, 5-8.

PLATE I



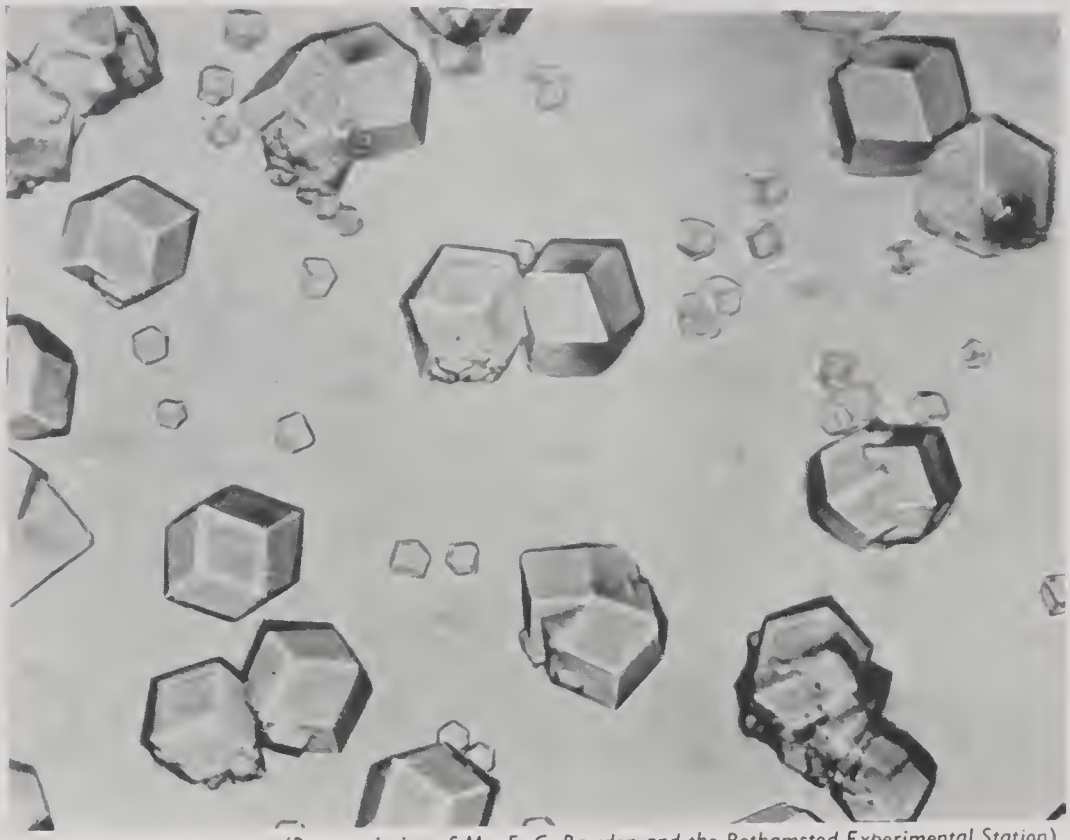
1. The cause of Potato Blight. A much enlarged glass model of the fungus *Phytophthora infestans*.



(*By permission of Dr. K. M. Smith*)

2. Photomicrograph of the sucking parts of an aphis penetrating the tissue of a leaf. The virus is injected with the saliva into the plant while the insect is feeding.

PLATE II



(By permission of Mr. F. C. Bawden and the Rothamsted Experimental Station)

1. Crystals of Tomato Bushy Stunt virus greatly enlarged.

2. Carrot attacked by Broom Rape (*Orobanche sp.*).

1. Wheat ears showing frost injury.

2. Field bean—frost injury followed by the Chocolate Spot disease (*Botrytis sp.*).

PLATE IV

(By permission of Mr. A. W. Oldershaw)

1. The effect of chalk on sugar beet on acid land in East Suffolk. Foreground—unchalked ; Background—5 tons of chalk applied 10 years previously.

(By permission of Dr. G. A. Cowie)

The effect of chalk on sugar beet growing in a light, acid soil at Tunstall, Suffolk. Left—chalked ; Right—unchalked.

Correns, Tschermak and De Vries. In the period between then and now great advances have been made in the scientific breeding of farm animals and crop plants.

The study of the plant and its environment, or ecology as it is termed, is of much importance, and it is becoming more and more appreciated. It is true, of course, that man, by intervening and applying the requisite amount of heat, light, water and mineral salts, can induce most plants to grow and complete their life cycle, but in the natural state, without artificial aids, they will not thrive to the best advantage unless they are grown in the particular environment to which they are accustomed. Although the common crop plants of this country will grow on most soil types, except those that are waterlogged or very deficient in lime, they do better on some soils than on others. Thus, beans are essentially a heavy-land crop, whilst turnips and swedes are better adapted to lighter and medium soils containing plenty of lime. Barley, a surface feeder, depends more upon the physical state of the soil than its inherent fertility, and so prefers the lighter types. Wheat, on the other hand, is better suited to the heavier types and medium loams, as it is a more voracious feeder, and quality is regarded as less important than with barley.

Most farmers are aware of certain fields on their farm—or on a neighbour's—where a particular crop usually does exceedingly well, and can be depended upon to give a high yield when its turn comes round again in the sequence of cropping. It is, as it were, "at home" and well adapted to the conditions of its environment. Unfortunately this knowledge often leads to disaster, for the temptation arises to take the same crop, or allied ones, too frequently on the same field, often year after year in succession. Disease then appears, the land is robbed of its clean bill of health, the crop fails and the soil becomes "sick." Present originally in small quantity, or perhaps accidentally conveyed there, the causal agents of disease multiply, accumulate in the soil and gain the ascendancy. Take-all of wheat and barley appears, Clover Rot, Bean Rot, and the wasting and pernicious maladies of potato and sugar-beet "sickness." It should be noted, therefore, that not only do crop plants thrive better in some situations than they do in others, but also parasitic

organisms, for they too have become adapted to the conditions of particular environments.

Although it is well known that the common crop plants have their preferences for particular soils, and that the yield and quality may be higher on one type than on another, it is often not generally realised that even the different varieties and strains have their likes and dislikes and do better in some localities than in others. In the past 40 years or so since the rediscovery of Mendel's Laws of heredity, and the publication in 1903 of the work of Johannsen on pure line selection, strains have been selected or bred to meet the special requirements of various soil textures and standards of fertility.

At research stations throughout the world, plant breeders are striving to improve the yield and quality of food plants and to produce types immune from or highly resistant to disease. At the Plant Breeding Institute, Cambridge, England, it is the cereals that have been studied extensively. It was at Cambridge that Biffen produced the famous light-land wheat Little Joss, a variety resistant to Yellow Rust, and also Yeoman, a strong variety of high milling and baking quality, a wheat best suited to heavy land of high fertility. This pioneer work was continued by Engledow and his colleagues, and Holdfast was bred—a variety shorter in the straw with a better resistance to "lodging," and doing best on highly-fertile medium and heavy soils. Steadfast followed, a wheat with a high degree of resistance to Yellow Rust but shorter and stronger in the straw than Little Joss, and most "at home" on medium soils of average fertility. Yeoman, Holdfast, Steadfast, are these names symbolic, a lasting pledge from the plant breeder to the farmer? At other research centres in the British Isles, notably at the Welsh Plant Breeding Station where Stapledon and his co-workers have investigated the agricultural values of the various strains of red clover and grasses, the scientific plant breeder is selecting or breeding the types best suited for particular environments.

It should be an axiom of sound farming practice, therefore, to choose a variety that is best suited to the soil texture and the standards of fertility. Advice on the most suitable variety can usually be obtained from the District Advisory Officer, the local Farm Institute, or the Provincial Advisory Centre, and it is

based on carefully conducted investigations. These may be simple field trials carried out by local authorities, or part of a wider investigation made by the National Institute of Agricultural Botany, Cambridge. In the latter event the information given is based on yield trials made over a number of years at representative centres in the British Isles. Work of this kind is steadily progressive and in years to come will be of inestimable benefit.

When the suitability of a variety has been decided, the next consideration is the quality of the seed sample. Is the germination capacity high and uniform, or is it low and irregular? Is the sample free from inert matter, chaff, dust and broken seeds? Are weed impurities present? A poor or ragged germination is bad enough, as a thin stand follows and reduced yields result; but, apart from this, if weeds gain entry the land becomes foul. From the farmer's point of view, a weed is any plant growing in the wrong place: thus wheat is a weed if present in a sample of barley intended for malting purposes, and Little Joss if present in a sample of Yeoman grown for seed.

The popular meaning of the term weed, however, is a plant not usually cultivated, and the seed analyst groups these into two classes, injurious weeds and other weeds. Five of the worst kinds of weeds have been scheduled in the Seeds Act, 1920. They are:—

Docks and Sorrels (*Rumex* spp.)
Cranesbills (*Geranium* spp.)
Wild Carrot (*Daucus carota* L.)
Yorkshire Fog (*Holcus lanatus* L.)
Soft Brome Grass (*Bromus mollis* L. et spp.)

Seed containing more than 5 per cent. by weight of these may not be offered for sale or be sown. There are other weeds almost as harmful, however, and consequently care should always be taken when selecting the seed sample, lest new weeds colonise the land. There is a perpetual struggle between weeds and crop plants for living space, and when dirty seed samples are sown weeds usually win.

It is also most desirable that the seeds sown should be free from "seed-borne" diseases. If it is not clean, then precau-

tions should be taken and, when possible, the seed treated with a suitable dressing before it is sown.

Cheap seed is often dear at any price, and bad bargains of this kind are unfortunately only too common. High-quality seed, true to type, free from inert matter, weed impurities and disease organisms, commands its fair price. How, it may be asked, is the farmer to determine the important factors that decide the quality of seed, its purity and vigour of germination? The Official Seed Testing Stations test seed samples for the farmer's own information at the nominal fee of 6d. per sample.

The seed is sown and life quickens within it, young leaves unfold, and roots probe downwards, colonising the crevices of the soil. In the narrow confines of this living space, its life cycle is completed—unless, of course, disease intervenes or it fails to obtain sufficient food. It is time, therefore, to consider the environment of the green plant and its struggle for existence.

OFFICIAL SEED TESTING STATION
for England and Wales
HUNTINGDON ROAD, CAMBRIDGE.
Telegrams: Niab Phone Cambridge. Telephone: Cambridge 76341

Station No.
AA. 8345.
Any correspondence regarding this sample MUST REFER to the above Station Number

FINAL REPORT

on a sample described as

Red Clover Seed. ; marked A/4.

Sent by J. Smith, Esq.,
Pound Farm,
KILBINNIN.

S

Date received: 9/9/46. Date reported: 20/9/46

PURITY: 86.5 % GERMINATION: 60 % HARD SEED: 5 %

PRINCIPAL IMPURITIES:		Per Cent.
Injurious Weeds:	Geranium dissectum, Rumex crispus, Geranium molle.	.9
Other Weeds .. :	Plantago lanceolata, Sherardia arvensis, Lychnis alba, Centaurea nigra, Carduus arvensis, Petroselinum segetum.	2.2
Useful Species.. :	Trifolium repens, Lolium spp; Medicago lupulina, Trifolium hybridum.	2.1
Inert Matter .. :	Broken, Eaten & Sprouted seed, Dirt, Chaff, Ergot.	8.3

DODDER: No seeds of ------ seeded Dodder were found in 4 ounces.

ALFRED EASTHAM,
Chief Officer.

REMARKS: SEE OVER.

Fig. 1. An Official Seed Testing Station report such as would be received for a poor sample of clover seed.

Chapter Four

The Green Plant and its Environment

The air, which all animals and plants breathe, consists of a mixture of gases, and without these life, as we know it to-day, could not exist. The vital constituents are oxygen, nitrogen and carbon dioxide. Apart from these there are small quantities of certain inert gases, as well as water vapour, traces of chemical fumes, and variable impurities such as dust particles and microscopic organisms. The average composition is shown in the following table :

THE AVERAGE COMPOSITION OF THE ATMOSPHERE

Constituent	% by Volume	% by Weight
Nitrogen	78.03	75.51
Oxygen	20.99	23.15
Carbon dioxide	0.03	0.04
Inert Gases (argon, helium, krypton, neon, xenon) ..	0.95	1.30
Water Vapour and Impurities ..	Variable	Variable

Nearly four-fifths of the volume of the atmosphere consists of nitrogen, a very inert gas that, at ordinary temperatures, does not readily combine with other elements and does not support life or combustion. Nitrogen is of much significance to farmers, however, as it is the important constituent of nitrogenous fertilizers and protein food materials. Towards the end of the last century there was a " scare " that the supply of quick-acting nitrogenous fertilizers would soon be exhausted, for nitrates were obtained almost exclusively from the natural deposits on the western slopes of the Andes. It occurred there in the form of caliche and was found two or three feet below the surface of the soil. The material consisted mainly of nitrate of soda, earthy matter and various impurities. It was dug up, most of the impurities removed, and then sold as " Chili saltpetre," " nitre " or nitrate of soda.

At a meeting of the British Association in 1898, Sir William Crookes focused attention on this matter and pointed out that these natural resources could not be expected to last for ever, and that the time would come when there would be a dearth of nitrogenous fertilizers. He suggested that the classical experiment of Cavendish in 1785 should be applied to the commercial production of nitrates. By passing powerful electric sparks through the air the nitrogen and oxygen would combine to form oxides of nitrogen. These, dissolved in water, would give a mixture of nitrous and nitric acids which could be neutralised with lime to give calcium nitrite and nitrate. Seven years later nitrates were being made from the air ! By this, and somewhat similar methods, many hundreds of thousands of tons of nitrogenous fertilizers are now produced annually. As we shall see later, the fixation of atmospheric nitrogen can also be brought about by certain microscopic organisms.

Unlike nitrogen, oxygen combines readily with most other chemical elements, and often with such energy that light and heat are generated. Oxygen is a powerful supporter of combustion. For example, a glowing splinter of wood placed in a jar of oxygen bursts quickly into flames, carbon dioxide and water vapour are formed, and the wood burns away. The combustion is rapid, as it is when a fire burns on the hearth. Less obvious, however, is the combustion of food that occurs in all living plant and animal cells as a result of the breathing process termed respiration. This is a quiet burning, a continuous slow combustion, and when it ceases life is at an end. There is an obvious emanation of light and heat when a fire burns, but energy is also released as a result of the combustion of food materials stored in plant and animal tissues, and carbon dioxide and water vapour are formed. It is the energy released by the oxidation of food that is vital for the maintenance of the living state. All living organisms, plants and animals alike, must breathe, and they obtain their oxygen from the air.

With animals the air enters the lungs during the intake of breath, and the oxygen it contains combines with the red

colouring matter of the blood, hæmoglobin, to form oxy-hæmoglobin. Oxygenated blood then circulates in the arterial blood-stream to all parts of the body, where the tissues utilise the oxygen for the combustion of food materials and waste products. This oxidation results in the release of heat and the formation of carbon dioxide and water vapour. It is this energy that maintains the body temperature and ensures the continuance of all vital processes. The carbon dioxide and water vapour are waste products, and they pass into the venous system, from which they are expelled by the lungs to the atmosphere. Animals, therefore, absorb oxygen from the air and return carbon dioxide to it.

Plants, too, must breathe to obtain the oxygen they require, but they have no special respiratory organs. In aerial parts of plants the air enters through special pores (stomata) in the skin (epidermis) of green leaves and stems, and also through air passages (lenticels) in the bark. It then diffuses through air spaces in the tissues and the oxygen is absorbed through the cell walls. It must not be thought, however, that it is merely the aerial parts of the plant that require oxygen. All parts of plants breathe—leaves, stems and roots alike. Indeed, if the aeration of the soil is poor, owing perhaps to faulty drainage or inferior cultivations, the tips of the roots and the root hairs are unable to obtain sufficient oxygen, with the result that growth is retarded and the plants become unhealthy. What happens to the oxygen absorbed by the living plant cells? It oxidises food materials, converts them into carbon dioxide and water vapour, and sets free energy that is used for the growth of the plant and the manufacture of complex foodstuffs.

As both animals and plants respire, it might be reasonable to assume that the supply of oxygen in the air is slowly being exhausted and the amount of carbon dioxide increased. This is not so. The composition of the gases in the atmosphere does not vary to any marked extent, and the percentage of oxygen remains relatively constant. There is, however, some slight variation from place to place in the carbon dioxide, the concentration being greater in the town than in the country, but the figures for any given locality do not vary very much, and the carbon dioxide does not continue to accumulate in

PLATE V

Photomicrographs of weed seeds scheduled in the Seeds Act, 1920 :
(*a*) *Rumex acetosella* ; (*b*) *Rumex crispus* ; (*c*) *Bromus mollis* ; (*d*) *Holcus lanatus*.
(*e*) *Daucus carota* ; (*f*) *Geranium dissectum* ; (*g*) *Geranium molle*.

PLATE VI

Crown Gall of sugar beet (*Bacterium tumefaciens*).

the air, and neither does the oxygen become diminished. Why is this ?

At the end of the eighteenth and the beginning of the nineteenth century a notable discovery was made. It was found that the carbon in plants (and every organic substance contains carbon) was obtained from the carbon dioxide in the air, and not from the humus in the soil, as had previously been supposed. This discovery was due to the researches of Ingenhouss, Senebier, Théodore de Saussure and Sachs, but at the time it was not readily accepted.

Only plants that are green, however, can obtain their carbon in this way, and they do so only in the daytime. The greenness of plants is due to a remarkable colouring matter, chlorophyll, that is contained in minute granules (chloroplasts) present in the leaf cells. When there is a sufficient intensity of light these green cells absorb carbon dioxide from the atmosphere and combine it with water to form carbohydrates, substances such as sugar and starch. In the process (called carbon assimilation or photosynthesis) oxygen is set free and escapes to the outside air. This is a miracle of manufacture. Each green cell is a minute factory trapping the energy of sunlight and locking it up in food. Respiration is the key that releases it again. It should be noted, however, that with green parts of plants in sunlight respiration does not involve any exchange of gases with the atmosphere, as some of the oxygen resulting from photosynthesis is used. Further, in these circumstances, the carbon dioxide produced in respiration is used up in photosynthesis, which consumes 20 or 30 times as much carbon dioxide as is liberated in respiration during the same period.

It is true that civilised communities have not always possessed sugar in the refined state, but there is a philosophical attraction in wondering what would happen if some devastating disease destroyed the sugar cane and sugar beet, and the bee failed to produce honey. Would the plant breeder choose other plants and by selection increase their sugar content, or would industrial chemists imitate in all its exactitude the carbohydrate synthesis in a green cell—and produce sugar from the air ?

To summarise, let us compare side by side the two processes of respiration and photosynthesis :—

Respiration	Photosynthesis
Plants and animals	Green plants
All living cells	Green cells only
Night and day	Daytime
Oxygen used	Oxygen set free
Food oxidised	Food manufactured
Energy set free	Energy absorbed from sunlight by chlorophyll and stored in food
Carbon dioxide formed	Carbon dioxide used
Water formed	Water used

Plants cannot live on carbon dioxide alone, however, for they need water and nutrient salts to make other foodstuffs such as protein. These are also necessary for the production of protoplasm, the viscous living substance in plants into which all nourishment is taken and from which all parts are formed.

Carbohydrates consist of carbon, hydrogen and oxygen, but most proteins contain in addition to these elements nitrogen, phosphorus and sulphur. Examples of proteins are the gluten in wheaten flour and the casein in milk. Proteins are very complex organic compounds built up of units called amino-acids. Emil Fischer, in 1901, was the first to devise a technique to isolate and identify several of these amino-acids and to state their approximate content in certain proteins he was investigating. The nitrogen that the plant needs for making protein is not obtained as a gas from the air, but, with certain exceptions, that will be noted later, from the soil. It is not obtained, however, from the mineral particles derived from the rocks from which the soil originates, but from the dead remains of plants and animals. It is the presence of this organic matter that confers a living nature upon the soil, for it is the food of a multitude of living organisms. Indeed, it has been estimated that 500-1,000 million bacteria may inhabit one ounce of soil !

Locked up in the decaying matter is the nitrogen that the plant requires ; but how does it become available, for the roots cannot absorb it in the complex protein state in which it exists ? It was discovered that, as the organic matter decays, the protein and other nitrogenous substances undergo a series of

changes. First a process of ammonification occurs, resulting in the formation of ammonium compounds, and then one of nitrification, that leads to the formation of nitrites and subsequently of nitrates. These changes are brought about by soil bacteria. Various kinds are concerned in the formation of ammonium compounds, but the oxidation of these into nitrites is caused by *Nitrosomonas* and *Nitrosococcus*, and the conversion of the nitrites into nitrates by *Nitrobacter*. All nitrates are soluble, and it is in this form that the plant obtains the bulk of the nitrogen it requires. These and other beneficial types of bacteria will not thrive in sour or badly-drained soils or those in which the air is stagnant. If adverse soil conditions prevail then harmful organisms predominate and a lower standard of fertility results. For example, certain kinds of bacteria attack compounds containing oxygen and nitrogen, utilising the oxygen for their own vital purposes and releasing the nitrogen to the air. This process of denitrification occurs under anaerobic soil conditions, that is, in soils where the air is stagnant and free oxygen not available. When the soil ceases to breathe there is no profit in the land.

Although the majority of plants obtain their nitrogen in the form of nitrates, there are some, the *Leguminosae*, that utilise the nitrogen of the air. Members of this natural order are peas, beans, vetches, clover, trefoil, sainfoin, lucerne and lupins, and they are all rich in protein. The discovery that these plants, besides making use of the nutrients in the soil, can also use the nitrogen of the air, was made in 1888 by Hellriegel and Wilfarth. It had been known long before this date, however, that clover and related plants in some way benefited the crops that followed, especially cereals, and that the fertility of the soil was enhanced.

The members of the order *Leguminosae* are extraordinary plants because they are able to live in natural harmony (symbiosis) with certain soil bacteria. It is a strange union, for the organism concerned, *Rhizobium leguminosarum* (synonyms *Bacillus radicicola* and *Pseudomonas radicicola*), penetrates into the plant roots and forms peculiar nodules on them, and in these they live without detriment to their host. The plant supplies them with food material in the form of carbohydrates and, in payment as it were, the bacteria absorb the free

nitrogen of the air and convert it into nitrogenous substances that are made available to the plant. As these crops are rich in protein, it follows that when the stubbles are ploughed in, the nitrogen reserves of the soil are increased.

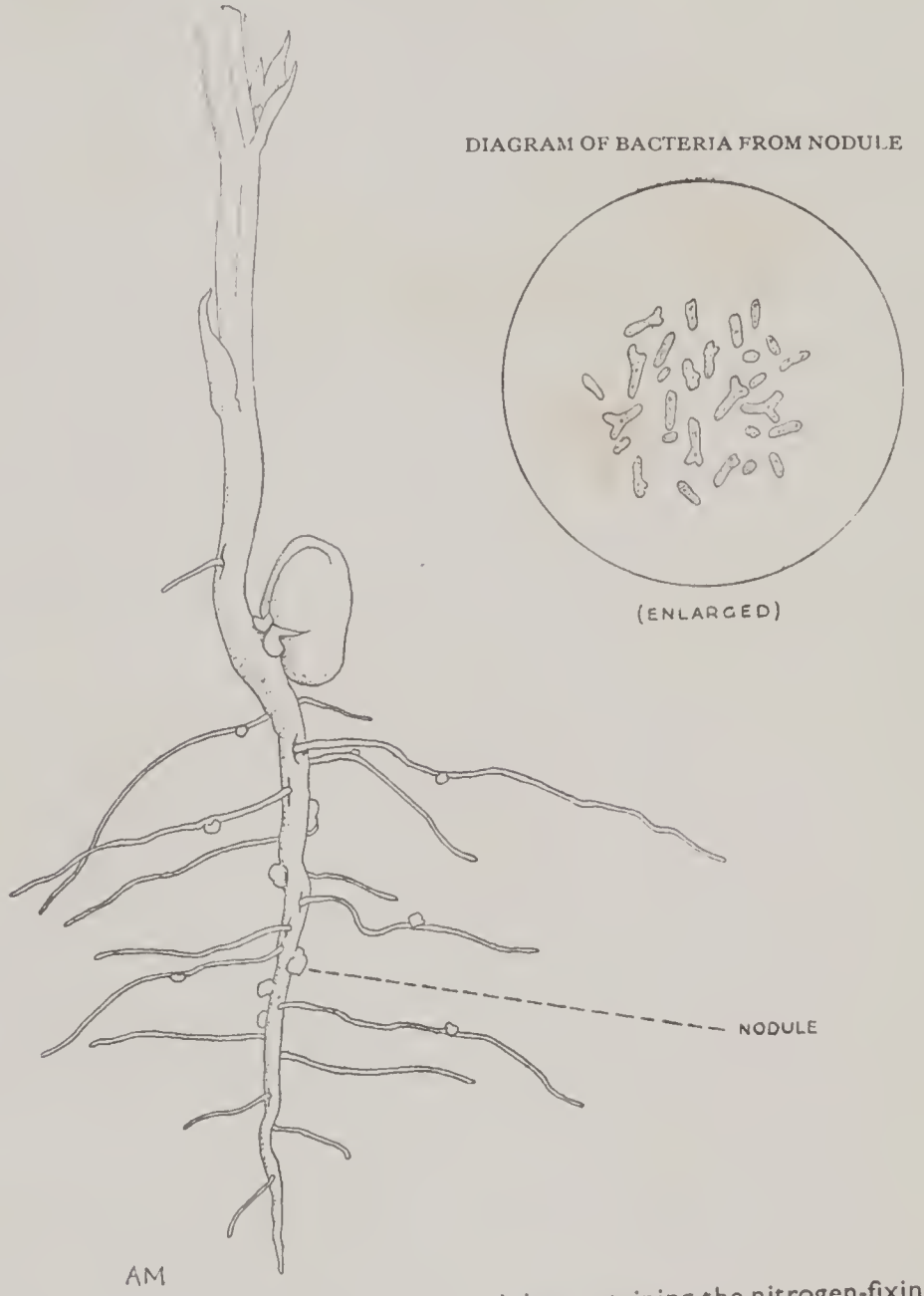


Fig. 2. Diagram of a bean root with nodules containing the nitrogen-fixing organism *Rhizobium leguminosarum*.

Fertility is thus intimately connected with the microflora of the soil, and especially with the many bacteria found there, but their effect upon the plant may be largely indirect. Some species, however, are actively pathogenic to plants, but for-

tunately these are few in number. Examples are *Bacterium carotovorum*, which causes Soft Rot of carrots and other plants; *Corynebacterium michiganense*, the cause of Bacterial Canker of tomato ; and *Bacterium tumefaciens*, which produces Crown Gall in a wide range of cultivated plants.

At this stage it is not out of place to inquire into the sequence of events when protein-containing foods are eaten, and to determine what happens to the nitrogen they contain. The digestion of food is brought about by enzymes, and the complex foodstuffs are broken down into simpler products. The proteins are split up eventually into amino-acids and are absorbed into the blood-stream where a part of them is used to build up flesh or repair tissue. The nitrogenous material not required is conveyed by the blood to the liver and converted into urea. It then travels in the blood-stream to the kidneys, where it is filtered off into the urine and excreted. The nitrogen does not remain in the form of urea, however, for certain bacteria convert it into an ammonium compound and this, in its turn, undergoes nitrification to nitrites and nitrates. There is, therefore, a " cycle of nitrogen " in nature, a building up and a breaking down, creation and decay, the formation of plant and animal proteins and their decomposition into simple inorganic nitrates that are available to build up life again.

Besides carbon and nitrogen, and the hydrogen and oxygen of which water is composed, plants require other elements for their nutrition. When a plant is carefully analysed by chemical and spectrographic methods many elements can be identified, but carefully conducted experiments have shown that all of these are not vital for its welfare. Crops vary in their food requirements, but some nutrients are needed in relatively large amounts, whilst only traces of others are necessary. Those used in larger quantities are usually referred to as " major " elements, whilst those used in much smaller amounts are described as " minor " or " trace " elements.

The major elements are nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. The first three, nitrogen, phosphorus and potassium, are extremely important, for they are intimately related to yield and quality of produce, and as they are used in relatively large amounts they tend to become

exhausted from the soil. It is with these that the farmer is mainly concerned, and to avoid a run on the bank of fertility he cashes in the gold of the muck cart, and also further credits the soil with nitrogenous, phosphatic and potassic fertilizers.

It must not be thought, of course, that fertility depends on fertilizers alone. A soil to be fertile must be in good heart, well-drained and cultivated, and—a matter of much importance—must have adequate resources of organic matter and lime. Not only is lime required because it contains calcium, an element essential to healthy plant life, but for other reasons. Lime neutralises acidity and keeps the soil "sweet." It is necessary, too, for the well-being of useful soil bacteria and the release of food reserves in the soil. It has also a beneficial effect on the texture of many soils. When lime is deficient, or in low supply, weeds such as spurrey and sheep's sorrel appear, and the Club Root disease of swedes and related crops. When they are noted, therefore, a lime-requirement test should be carried out, and the deficiency made good. Lime, however, is not a fertilizer in the usually accepted sense, and "lime, and lime without manure, will make both land and farmer poor."

When the "major" elements that the plant needs are not available, or are in low supply or in incorrect proportion, signs of unthriftiness are seen in the crop, and various symptoms characteristic of malnutrition appear. The shoots and stems may be stunted, the root growth restricted, or the leaves turn yellowish-green, yellow, orange, bronze, red or even purple.

The "minor" or "trace" elements necessary for plant nutrition are iron, manganese, boron, copper, zinc and molybdenum; as the term "trace" implies, they are required in minute quantities only. Most soils have an adequate supply, but occasionally a particular element is missing, is used up, or is not present in a form in which it is readily available to the root system. When this occurs crops become unhealthy and signs of certain ailments appear. These are usually termed deficiency diseases, but the term "disease" is not particularly apt, as they are not diseases in the true sense, but disorders due to incomplete nutrition. It is customary, however, to consider these ailments in a different category from the starvation effects produced by low supplies of nitrogen, phosphorus and potassium.

In recent years much research has been done on the mineral requirements of plants, especially at Rothamsted, where the effect of boron on the nutrition of certain crops has been studied, and at the Long Ashton and East Malling Research Stations, where the effects of both " major " and " trace " elements have been investigated, notably in connection with the nutrition of fruit trees. Researches here, and at other centres, have provided much valuable information that has led to the prevention of certain ailments, the causes of which were previously unknown. For example, when the roots of sugar beet are unable to obtain boron, the beet plant suffers from a condition known as Heart Rot, in which the central leaves blacken and die, and a rot sometimes develops at the crown. When manganese is deficient, however, sugar-beet plants show entirely different symptoms, for Speckled Yellows appears, a disease characterised by a pronounced yellow mottling of the leaves. By the application of a salt containing the appropriate trace element, borax for Heart Rot and manganese sulphate for Speckled Yellows, both of these diseases can be prevented. It should be noted, however, that " trace " elements are required in very small quantities only, and harm may result if they are used in excess. Trace elements may also occur naturally in excess, and lead to toxic effects. For these reasons expert advice should always be sought in the diagnosis and prevention of deficiency diseases.

In the soil, locked within the mineral particles and decaying organic residues, are the elements that plants need for nutrition. By the weathering of the original rock system—a complicated process involving many changes of a physical and chemical nature—soil particles are formed and the minerals they contain are slowly brought into solution. In this soil water, absorbed by the root hairs, are the nutrients on which plant life depends. From the simple inorganic constituents it contains, and the carbon dioxide of the air, are made complex organic foods, the sustenance of man and beast.

Suppose disease intervenes, however, what then? It is time to consider the nature of fungi, and the ways in which the " seeds " of disease are disseminated.

Chapter Five

Fungi and Spore Dispersal

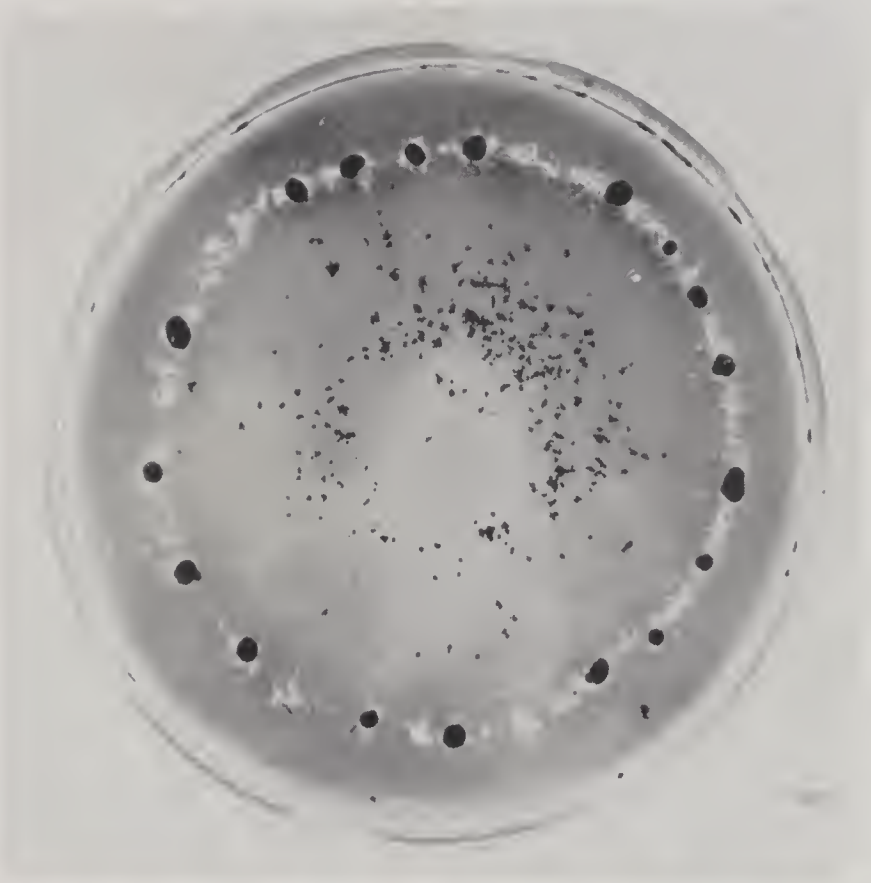
The fungi are a group of plants comprising some 37,000 species, which, without exception, are devoid of chlorophyll. As already noted, green plants are able to make the organic foods they require from the carbon dioxide in the air and inorganic salts in the soil, but fungi are unable to do this as they have no green colouring matter. They are forced, therefore, to use food already manufactured by plants and animals. Fungi that obtain this nutriment from a living source are described as parasites, and they are causal agents of disease. Those that feed on the dead remains of plant and animals are termed saprophytes, and they cause decay of organic matter.

For example, species of *Puccinia* (that cause the rust diseases of cereals), and *Actinomyces* (some of which cause disease in animals) are parasitic, for the food is taken from a living source. The blue-green mould *Penicillium*,* so often found growing on leather articles stored away in damp cupboards, is saprophytic, however, for its food is absorbed from dead animal matter. It may be noted that other species of this same fungus are responsible for the ripening process and flavour of certain cheeses, e.g., Stilton. In the making of blue-veined cheese an open texture is retained, so that the mould may develop in the veins during the ripening process.

When a plant or animal completes its life cycle, or is killed prematurely by a parasite, it is soon beset by saprophytes, and decomposition and decay take place. Although many fungi are either strictly parasitic or saprophytic, there are some with both tendencies. *Botrytis*, the common Grey Mould fungus, is able to obtain a good living from plant débris, but it is also capable of seeking this on a healthy bean crop. A fungus of this type that can cause disease, but can also exist on material other than the living cells of a host (a term that is used to denote any living organism that harbours a parasite), is

* From the species *Penicillium notatum* penicillin is obtained.

PLATE VII



a

b

The Clover Rot fungus growing on synthetic medium :
(a) in a petri dish. (b) in glass tubes plugged with cotton wool.

PLATE VIII

a

b

Models of the summer and winter stages of a species of *Erysiphe* greatly enlarged. One species, *Erysiphe graminis*, is the fungus causing Powdery Mildew of cereals :
(*a*) summer stage. (*b*) winter stage.

PLATE IX

1. Apples covered with pustules of the Brown Rot fungus *Sclerotinia fructigena*.

2. Spores of *Sclerotinia fructigena* on a wasp's leg.

PLATE X

1. Scab lesions produced on apples by the fungus *Venturia inaequalis*.

2. Photomicrograph of *Penicillium notatum*.

termed a *facultative* parasite. Many fungi, however, are entirely dependent for their continued existence on contact with the living cells of a specific host. These are described as *obligate* parasites ; typical examples are the fungi that cause the powdery mildew and rust diseases of farm crops.

It is evident, therefore, that the food requirements of fungi are very variable, some having catholic tastes and others more specialised needs. Many fungi, excluding obligate parasites, can be grown on synthetic media and their characters and nutritional needs studied. The composition of these media varies slightly according to the organism grown, but carbon is always supplied in the organic form, often as sugar. The other nutrients are inorganic salts, nitrates, phosphates, etc., but organically-combined nitrogen is sometimes added. The medium may be used in either the liquid or gel form ; if the latter, it is usually made into a jelly by using agar, a substance obtained from certain algae. When prepared, the medium is standardised, and to prevent contamination by extraneous organisms it is kept in glass tubes or flasks plugged with cotton wool, or in Petri dishes with glass covers.

To investigate the mode of growth of a particular microscopic fungus, the various phases of its life cycle, and those conditions best or least suited to its development, a culture is made. This is done by inoculating the medium with the spores or hyphae of the organism. It is by cultural methods that the food requirements of fungi have been studied, and as far as is known the following elements are necessary for their nutrition : carbon, hydrogen, oxygen, nitrogen, potassium, phosphorus, magnesium, sulphur and very small amounts of iron, zinc and copper. In recent years, however, it has been discovered that, besides these, certain complex organic compounds known as " growth substances " are also needed. (Similar substances have been found necessary for growth responses in green plants.)

The structure of a fungus must now be considered. The vegetative body or thallus is a mycelium composed of thin-walled hyphae, minute tubes filled with protoplasm. These delicate filaments may be divided by cross walls or remain undivided, i.e., septate or non-septate. At the tips of the hyphae continuous growth takes place, and there are sometimes

excreted enzymes that dissolve cell walls obstructing their passage. In some instances, toxic substances are also produced and the cells killed. The behaviour of the hyphae varies with the species concerned ; some grow on the surface of the host and others penetrate deeply into it ; when they penetrate deeply, probing between the cells, they are described as intercellular, but when they pierce through the cells, as intracellular.

Intercellular hyphae form small peg-like branches that push their way into the living cells ; these organs are termed haustoria and they absorb the cell sap. Hyphae that ramify over the surface of leaves and stems, but do not penetrate further, are similarly equipped and obtain their nourishment from the epidermal cells. When the mycelium is intracellular, however, there are no special absorbing organs, and the food enters through the walls of the hyphae. Fungi that spread over leaves and stems are harmful, for, although they seldom kill the tissue, they slowly drain away the cell sap and, by smothering the green cells, retard or prevent photosynthesis. This checks the growth, weakens the plant, and reduces the yield and quality of produce. Fungi of this type are those causing the powdery mildew diseases and, in some seasons and on certain soil types, they are often very severe, particularly on cereals and more especially when these crops have received an excessive amount of nitrogen.

It might be thought that parasites that probe deeply into the tissues immediately kill the cells with which they come into contact, but this, although of frequent occurrence, does not always happen. When cells are killed by invading hyphae the affected part is usually marked by colour changes, and a lesion develops. Thus, when the green cells of barley leaves are killed by the fungus *Helminthosporium*, longitudinal brown stripes appear. These symptoms are so characteristic that the common name given to the disease is Leaf Stripe. A similar complaint affects oats, and both cause much loss unless preventive measures are taken. Similarly when the haulm of field beans is parasitised by *Botrytis*, and the infection is of a mild or " non-aggressive " type, well-defined, chocolate-coloured spots are seen—the Chocolate Spot disease. Sometimes, however, on this same host *Botrytis*

assumes an " aggressive " form and, instead of chocolate-coloured spots appearing, the leaves and stems rapidly turn black and die.

All living organisms strive to reproduce their kind, and the fungi are no exception. Unlike green plants that produce seeds for this purpose, fungi form spores. A wide diversity of types of spores exists and many are developed in special fruiting bodies. Some of these are most minute, but other fructifications are of considerable size ; common examples of the latter are puff-balls, mushrooms, toadstools and the bracket-shaped fungi found growing on dead and living trees. With few exceptions these larger fruiting bodies are of little interest to the plant pathologist, for they are mostly saprophytic. Spores vary very considerably in size and shape, but they are all microscopic, and to measure their different diameters the unit adopted is μ (1/1000 of a millimetre), the measurement being made with a microscope fitted with a micrometer eyepiece.

Spores may be produced by sexual or asexual methods, some fungi forming asexual spores only, others sexual, while about one-third reproduce by both methods. When both occur, there are two distinct phases in the life cycle, the asexual or imperfect, and the sexual or perfect phases. These are sometimes referred to as " summer " and " winter " stages. When both are present the asexual spores, or conidia as they are called, enable the fungus to propagate rapidly, and, if conditions are favourable for their germination and subsequent development, epidemics of disease result. These " summer " spores, once they are released, however, are usually short-lived, as they are ill-adapted to withstand adverse weather conditions. For a limited period they colonise space, depending upon chance to bring them to their host, but as they are then nakedly exposed and away from their host, a very heavy mortality occurs. Towards the end of the asexual stage a resting or " winter " phase develops, and other spores are produced by sexual means. These are protected by various devices until such time as they are released. For example, the cell walls may be much thickened or the spores developed in special fruiting bodies. When the perfect stage is absent or rare, the conidia may be protected by similar means, or the fungus may survive as dormant mycelium.

As in many fungi there is a stage in which a sexual process takes place, it follows that variations may occur in the progeny, for fungi also conform to Mendelian principles. Such progeny may appear to be identical in form and structure when examined under the microscope, and yet may differ in their physiological and pathological characters. This is especially so in those obligate parasites that cause powdery mildew and rust diseases for, in these, distant physiologic races are produced. This is well illustrated by the fungus causing Black Rust of wheat, for nearly two hundred races have been defined, and these vary considerably in their pathogenicity on the different wheat varieties. Some races may have little or no effect on a particular variety, but other races may effect it markedly. Immunity may be due, therefore to the absence of physiologic races to which the host is normally susceptible.

This apparent immunity, however, is not true resistance but an example of disease escape. When climatic conditions are suitable for a rust attack, therefore, the intensity of disease will be influenced by the variety grown and the particular physiologic race or races that are present, and these will vary from place to place, and country to country. In the British Isles, Black Rust of wheat is of little consequence, but it is not so elsewhere, for it was estimated that in Canada in 1916 this disease caused a loss of 100,000,000 bushels. It was largely as a result of this epidemic that Government action was taken and an intensive study of the disease begun. The Dominion Rust Research Laboratory* at Winnipeg was established, and a group of scientists concentrated on every aspect of the rust problem; but they were not alone in their researches, for similar studies were in progress at research centres in the United States. It says much for the skill and patience of the plant pathologists concerned (Stakman and his co-workers in America and Craigie and his colleagues at Winnipeg) that eventually the salient points of the problem were mastered, and plant breeders, using the information gained, were able to produce varieties resistant to Black Rust.

To the uninitiated the onset of a fungus disease is always mysterious. How does disease arise? By one means or another, the spore of some parasitic fungus (the " seed " of the

* Now the Dominion Laboratory of Plant Pathology.

disease) comes into contact with the plant. If moisture is present and temperature conditions are favourable the spore germinates, but no shoot and root appears, merely a minute tube (or tubes). This, the germ tube, grows at its tip and searches for food : but, as with the seed, so it is with the spore. " . . . some fell upon stony places . . . and when the sun was up, they were scorched ; and because they had no root, they withered away . . ." If conditions are favourable, however, and the spore has encountered the right host, the hypha penetrates into the plant tissues and infection results.

When the minuteness of spores is considered, it might be reasonable to assume that the chance of a specific disease organism coming into contact with the appropriate host is remote. This would be so but for one thing, the prodigality of fungi in the mass production of spores. Buller* estimated that 1,800,000,000 spores were discharged from the gills of one mushroom in forty-eight hours, and that in the same period the Shaggy Cap fungus released 5,240,000,000 ; but these numbers seem almost trivial when compared with the contents of a large Giant Puff-ball he examined, for he estimated that this contained 7,000,000,000,000. So prolific are these and similar fungi that it would seem inevitable that, " started like mist from the wet ground cold," the earth should be carpeted with them. This does not occur, however, for they too (although they are saprophytes and scavengers) are selective, not only in their nutritional requirements but in their need for specific environments—they cannot grow anywhere and on any dead matter.

Once the spore has been released from the parent body, it is often borne away by the wind and its ultimate destination is then a matter of chance. To what height may spores be carried, and how far can they travel ? They have been caught on traps exposed from aeroplanes at altitudes as high as two miles and, as we shall see later, circumstantial evidence indicates that they may travel in air currents for long distances. The methods adopted for trapping spores vary, but usually they involve the exposure of glass slides that have been very lightly treated with a thin film of vaseline or some other

*Buller, A. H. R. (1907). *Researches on Fungi*, Vol. 1. London : Longmans Green & Co.

adhesive substance. The slides are carefully prepared and kept in airtight containers until such time as they are exposed. After exposure they are immediately returned to their containers (to prevent further extraneous contamination) and later brought to the laboratory where they are examined microscopically.

By means of air and ground spore-traps much useful information has been obtained on spore dispersal and the spread of plant diseases, notably in North America, where plant pathologists, in co-operation with pilots of the Canadian Wing of the Royal Air Force, investigated the spread of Black Rust of wheat. The Mississippi Valley and the Prairie Provinces of Canada embrace an almost continuous cereal-growing belt, which extends from the Gulf of Mexico to the Peace River Valley in northern Alberta, the crops maturing in succession from the south to the north. The results of field surveys for Black Rust, when correlated with the rust-spore content of the air at different locations, indicated that the earliest infections in the prairies were due to wind-borne spores which had been swept up from further south. It would seem, therefore, that when Canadian epidemics occur, they result from a northern advance of the disease from the Upper Mississippi Valley.

It must be remembered, however, that the presence of rust spores does not necessarily imply that infection will take place, for increase and spread of the disease is much influenced by weather conditions. Water is required before the spores can germinate, and for any mass germination the plants must be covered with a film of moisture for twenty-four hours. If the film dries out before the germ tubes have penetrated into the tissues, they are killed and infection does not take place. When "spore showers" occur, and conditions are favourable for germination and subsequent infection, epidemics occur. When vast acreages of one crop are grown, therefore, there is always a great danger that an epidemic of disease will arise : if certain diseases are present, the spores will be swept upwards and deposited further and further afield. In England, where various crops are grown in rotation as well as on relatively small acreages, there is less chance of the air becoming heavily loaded with spores of a particular type ; further, spores that are present have less chance of meeting

the appropriate host, and if they should meet it, the weather conditions may be unfavourable for infection.

There are many ways in which the spores of parasitic organisms are brought into contact with their host. A wasp alights on a rotting apple and the spores of the Brown Rot fungus become entangled in the hairs on its legs. It flies away and then, settling on a healthy apple, punctures the skin ; the Brown Rot spores infect the wound and the apple starts to rot. An aphis sucks the sap from an apple leaf infected with Scab, and the spores adhere to it. Later these are deposited on a healthy leaf. Rye flowers become infected with the Ergot fungus, and a sticky, sweetish, " honey-dew " containing numberless conidia (the spores of the " summer " stage) is exuded. When insects visit infected flowers, they transfer the spores to healthy ears, and the disease is spread further afield.

The spores of most saprophytes, and many parasites, are well adapted for wind distribution, but this is not so for all spores. Many depend upon water for their dispersal, and consequently on rain—or a combination of rain and wind. Potato Blight is caused by a water-loving fungus of this type that produces sporangia. These are spore cases that contain zoospores, each provided with two delicate motile hairs (cilia) that enable them to swim about in drops of water. The sporangia fall from the stalks that bear them, or are knocked off during rainstorms, and the zoospores are liberated and swim about in the water-film covering the foliage. When the weather is damp and " muggy," and the film of water on the leaves persists, the zoospores send out hyphae, and these ultimately push their way into the internal tissues of the leaf. Once an entry has been gained, the symptoms of Potato Blight appear, and if weather conditions continue to favour the fungus an epidemic may result. If the leaves dry quickly, however, and dry conditions prevail, the spores are killed before the germ tubes can enter the leaves, and Blight is averted.

Some fungi develop their spores in special asexual spore cases known as pycnidia, but these too require water for the release and subsequent dispersion of the spores that they contain. The fungi causing Leaf Spot of celery, Canker of swedes, and Blackleg of sugar beet are typical examples.

Rain, besides providing the necessary moisture for germina-

tion, also serves another purpose, for it dislodges the spores from the stalks on which they are borne and scatters them. It is not generally realised that raindrops at their point of impact exert a considerable force, and when they fall on a spore mass (pustule) scatter the spores over a relatively wide area. The effect is comparable to a minute bomb that, on bursting, projects its fragments in all directions; but in this instance the fragments are minute water-droplets loaded with spores. The area covered by them depends upon various physical factors—the size of the original drop, its weight and shape, the viscosity of the air, and the surface and angle of the medium on which it impinges. The results obtained from some simple laboratory experiments indicate the extent to which the spores are dispersed. A drop of water, falling from a height of 13 feet on to a diseased leaf on which *Botrytis* was growing, radiated small splashes over an area of 3 sq. yd., and in one minute splash (approx. 3 sq. mm.) 156 spores were counted.

Had this occurred in a crop of field beans, some of the spore-containing droplets would have been deposited on the leaves within this area, and it is probable that the foliage would have become infected with Chocolate Spot. This, however, is merely one drop of water falling on to one pustule. What might happen during a rainstorm? Spores of another fungus were placed in a shallow, uncovered, glass dish and exposed during a shower of rain. When this ceased after ¾ hour, spore traps, that had previously been arranged at various distances from the dish, were examined. It was estimated that an area of at least 346 sq. ft. was contaminated with spores. It is probable, however, that the area was even greater than this, for the further away from the source of the inoculum, the less likelihood there would be of spores being deposited on the traps at the greatest distances.

Is it to be wondered that diseases spread so rapidly when spores are produced in such prodigious numbers and dispersed by wind and rain? More often than not, however, they are lost in the immensity of space and, should they reach their host, they may not survive unless conditions are suitable for their germination.

Unfortunately there are ways more subtle than these

PLATE XI

1. Conidia of *Venturia inaequalis* on a leg of an aphis.

2. Ears of rye, barley and wheat attacked by Ergot (*Claviceps purpurea*).

1

2

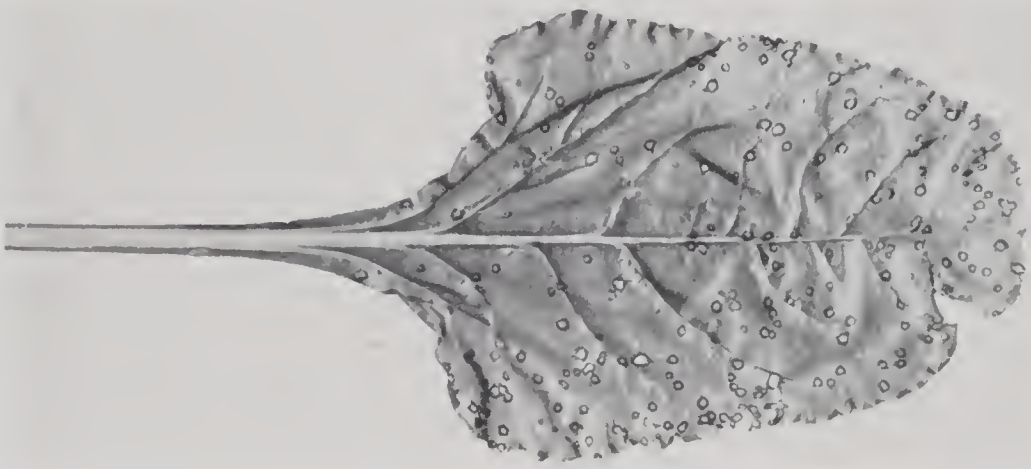
PLATE XII

1. A splash in a liquid—photographed by means of the "Kodatron Speed Lamp."
   (By permission of Messrs. Kodak Ltd.)

2. Model of a pycnidium liberating spores (greatly enlarged).

3. Splash pattern produced by a drop of milk falling on a milk film.
   (By permission of Mr. Harold E. Edgerton and the Massachusetts Institute of Technology)

PLATE XIII



1. Leaf Spot of sugar beet caused by *Cercospora beticola*.

2. A glass model of a species of *Cercospora* greatly enlarged.

PLATE XIV

a

Black Scurf and Stem Canker of potato (*Corticium Solani*) :

(*a*) The mycelial stage (*Rhizoctonia*) on the tuber.

(*b*) The perfect stage (*Corticium*) on the stem.

whereby spores are dispersed—means that markedly increase the possibilities of subsequent infection. Many causal agents of disease are present on the seed and, in some instances, inside it. These are the so-called seed-borne diseases, and they are responsible for much loss of farm produce. They are not considered in detail in this chapter, but some representative examples are given. Covered Smut or Bunt of wheat is a disease originating from spores present *on* the seed grain, but Loose Smut of wheat, an entirely different disease, is due to a fungus present *in* the seed grain. In the former the surface of the seed is *contaminated* by spores, but in the latter the grain is *infected* by a mycelium present deep inside the seed. A suitable seed disinfectant will kill spores on the surface of the grain, but it cannot penetrate (without killing the seed) to a fungus deeply embedded within it. Barley and oats are affected by somewhat similar smuts and, in addition, the Stripe diseases. These are also seed-borne but in this instance, although spores may be present on the seed, the chaff and husk are slightly penetrated by mycelium. This is not deeply embedded, however, as it is with the fungi causing Loose Smut of wheat and Loose Smut of barley, and it can be killed by modern seed disinfectants without injury to the vitality of the grain. Other seed-borne diseases of farm crops are Leaf Spot of celery, Blackleg of sugar beet and Canker of swedes, but these, and certain other diseases, will be referred to later.

When does the seed become infected or contaminated with disease organisms? Infection occurs at flowering time as the young seed is developing, but contamination usually takes place in the threshing machine. For example, Buller has estimated that one bunt ball may contain as many as 12,000,000 spores. If there were but one bunted ear in a crop of wheat, therefore, and this ear contained 30 bunt balls, some 360,000,000 spores would be liberated in the threshing machine and the healthy grain contaminated.

The spores and mycelia of other parasitic fungi are harboured in the soil. Take-all of wheat, Clover Rot, Bean Rot and various diseases resulting in the decay of the root system and the basal portion of the stem, arise in this way. Parasitic fungi are everywhere, and disease is inevitable unless precautions are taken.

Chapter Six

Classification

The use of the system known as *binomial nomenclature* was first developed by Linnaeus in his Species Plantarum in 1753. Under this system plants acquired two names, one representing the family group or genus, the other the particular species within that genus. The genus may be considered as a small natural group containing distinct species with comparable characters, while the species indicates a collection of individuals that, in the view of a competent authority, have the same constant and distinct features.

All living things are classified in an orderly and systematic way and each is given a generic and a specific name. The generic name for clover is *Trifolium*, and the various kinds are classified according to their species. Red clover is *Trifolium pratense*, and white clover, *Trifolium repens*. In a given species there are often a number of sub-species, each with its own particular characteristics and breeding true, and to describe these a varietal name is given. Thus the term "red clover" includes several sub-species, among which are Early-flowering Red (*Trifolium pratense praecox*) and Late-flowering Red (*Trifolium pratense serotinum*). In these sub-species or varieties there are often special strains. For example, with Early-flowering Red there are the following sorts : English Broad Red, Vale of Clwyd, Canadian, New Zealand, American and French. In the Late-flowering sorts, English Late, Montgomery, Cornish Marl, Swedish Late, American Mammoth, Norwegian, Danish and Altaswede.

In the same way that crop plants are named, so are the parasitic organisms that attack them, for each is given a genus and a species name. For example, clover suffers from Clover Rot, a disease caused by the fungus *Sclerotinia Trifoliorum*. This species injures clover and certain related crops, such as trefoil and beans, but it will not attack the apple to cause Brown Rot, for this disease is due to a different *species* of *Sclerotinia* having

different morphological characters : viz., *S. fructigena*. As with the flowering plants there may be varieties in a particular species, and within these there may exist specialised strains, forms or races. For example, the Powdery Mildew disease of wheat, barley, oats, rye and several species of grasses is caused by the fungus *Erysiphe graminis*, and on these host plants are races that differ in their capacity to cause infection, although morphologically indistinguishable. There are thus several distinct physiologic races of *Erysiphe graminis*.

Similarly, *Sclerotinia laxa* may produce a Brown Rot in the fruit of apple, plum and cherry, but the variety on apple, i.e., *S. laxa mali*, will not infect plum or cherry, and the variety on plum and cherry, i.e., *S. laxa pruni*, will not attack apples. The two varieties are morphologically identical but physiologically distinct. Physiologic specialization occurs in many of the fungi, including Ergot of cereals and grasses (*Claviceps purpurea*), Yellow Rust (*Puccinia glumarum*) and Black Rust of cereals (*Puccinia graminis*).

Classical among these is *Puccinia graminis*, which was first shown by the great Swedish pathologist Eriksson to exist in a number of physiologic varieties differing only in their capacity to infect various species of cereals and grasses. This work was further extended in America by Carleton and later by Stakman, and in Canada by Craigie and his co-workers at the Dominion Rust Research Laboratory at Winnipeg. It was found that not only did *P. graminis* consist of a number of physiologic varieties but that the variety on wheat, with which they first worked, consisted of many physiologic races. These differed in their capacity to infect a number of varieties of wheat. The method of identifying the races consists of inoculating them on twelve standard differential host varieties. The physiological differences between the races can then be inferred from variations in their pathogenicity.

The recognition of physiologic races and their reactions on varieties of crop plants is of inestimable value to the plant breeder faced with the task of breeding for resistance to disease.

Here it must be remembered that as a sexual process occurs in many fungi there is the possibility of " mating " between different physiologic races and the likelihood of variation in

the progeny. Thus the plant breeder in his deliberate search for resistant varieties tries to forestall the parasite that is producing new physiologic races by chance. It often happens that a new host variety is the means of segregating a new physiologic race, for example, the Canadian tomato variety Vetomold, which at the time of its introduction appeared completely resistant to the Leaf Mould fungus (*Cladosporium fulvum*), is now known to be susceptible to some races of the fungus. Similarly, in the search for potato varieties resistant to Blight (*Phytophthora infestans*), a number of distinct strains of the fungus have been detected, to one or more of which the commonly-grown varieties of potatoes are all susceptible. In the struggle between man and fungi active co-operation between plant breeder and plant pathologist is essential.

Students are often puzzled by the addition of an abbreviation following the scientific name of a plant or fungus, e.g., *Puccinia graminis* Pers., or *Sclerotinia Trifoliorum* Erikss., or even by more than one such name, as with *Phytophthora infestans* (Mont.) de Bary. These are referred to as the *authorities*, for they indicate the persons responsible for christening or naming the fungus. Thus Persoon was the authority who named the Black Stem Rust of wheat *Puccinia graminis*, and it was Eriksson who first described and named the Clover Rot fungus *Sclerotinia Trifoliorum*.

Sometimes, however, research by later plant pathologists adds to existing knowledge about the characters of a fungus and shows that a partial change of name is necessary or desirable. In such instances the authority for the original specific epithet is placed in brackets followed by the name of the authority who transferred it from one genus to another. For example, it was Montagne who named the fungus causing Potato Blight *Botrytis infestans*, but it was the great German pathologist Anton de Bary who showed that the fungus was really a *Phytophthora*. The name by which it is now known is *Phytophthora infestans*, or to give its complete name including authorities, *Phytophthora infestans* (Mont.) de Bary.

Other examples of fungi that have undergone change of name, and in consequence have more than one authority, are *Claviceps purpurea* (Fr.) Tul. causing Ergot of cereals and

grasses, and the Yellow Rust fungus *Puccinia glumarum* (Schm.) Erikss. & Henn. Students on occasion may wish to refer to the original description of a fungus to find details of the characters that distinguish it. They may find that these first descriptions are recorded in Latin, a seemingly unnecessary complication. The use of Latin, however, ensures a uniform method of description available to, and understood by, plant pathologists of all nations. By international agreement a description of each newly-discovered fungus must be given in Latin if it is to be valid. It is of interest to give a typical example of such a description—that given by Saccardo for *Cercospora beticola* Sacc., the fungus causing Leaf Spot of sugar beet. The description is taken from the Sylloge Fungorum Omnium Hucusque Cognitorum by P. A. Saccardo, Vol. IV, p. 457.

> 123 *Cercospora beticola* Sacc. F. Ven. Ser. V, pag. 189, F. ital. 2195 t. 669—Maculicola, amphigena ; maculis vagis, aridis, 2-3 mm. lat. v. amplioribus, saepius rufo-cinctis ; hyphis fasciculatis, saepius continuis, cylindraceis, 40-50≃4-5, apice nodulosis, fuscidulis ; conidiis acicularibus, 70-120≃3, dense septulatis, hyalinis.
>
> *Hab.* in foliis Betae vulgaris vivis et languidis in Italia bor., Gallia, Austria, Germania, Lusitania, America boreali et America australi.

To understand the broad basis of classification and how the three thousand odd genera containing some 37,000 species are classified, it is necessary to consider the principal methods of spore formation, for it is primarily upon these that classification is based. Many of the fungi possess at least two kinds of spores, one type suited for rapid dissemination or spread " in space," the other adapted for the survival of the fungus over periods of unfavourable conditions. The latter may be regarded as a means of spread " in time " and a way of ensuring continued existence. The summer spores, or conidia, are produced asexually, but the resting spores are generally preceded by a sexual process in which fusion of nuclei occurs. The spore form associated with this sexual process is referred to as the perfect stage.

There are three distinct types of perfect stage and associated spore forms, and it has been found convenient to base the main division of the fungi into classes upon the differences existing between these three types. The classes PHYCOMYCETES,

ASCOMYCETES and BASIDIOMYCETES are determined in this way. Into a fourth class, the Fungi Imperfecti, are grouped all those species for which a place cannot be found in the other three classes. The Fungi Imperfecti contain fungi that either possess no spore form at all, or the spore forms which they have are of the asexual or conidial type, and for which there is no known perfect stage. It may be, of course, that at a later date a fungus at first classified as one of the Fungi Imperfecti may be found to have a perfect stage ; it is then renamed and placed in the class to which the spore form of the perfect stage belongs. The fungus causing Black Scurf and Stem Canker of the potato was long known as *Rhizoctonia Solani*, but its perfect stage is *Corticium Solani* and it is now known by this name. Common examples of the Fungi Imperfecti are species of *Septoria*, *Colletotrichum*, *Fusarium* and *Rhizoctonia*.

The *Phycomycetes* are usually characterised by the presence at some stage in their life cycle of a special spore-forming organ known as a sporangium, in which spores are formed. The spores are often motile, for they possess cilia—minute hairs adapted for swimming. Many fungi in this class are aquatic, and among them is included the Potato Blight fungus (*Phytophthora infestans*). More primitive members of the *Phycomycetes* include *Synchytrium endobioticum*, causing Wart Disease of potatoes, *Spongospora subterranea*, the Powdery Scab of potatoes, and *Plasmodiophora Brassicae*, the cause of Club Root of the cabbage family. Formerly, *Plasmodiophora* and *Spongospora* were assigned to the *Myxomycetes* with which many of their characters have a close affinity. The fungi in which, at some stage in the life cycle, ascospores are produced in spore bags known as asci are grouped in the *Ascomycetes*; examples are *Venturia inaequalis*—the Apple Scab fungus, and *Sclerotinia Trifoliorum*—the cause of Clover Rot. The *Basidiomycetes* is a very large class and includes most of the larger fungi or " toadstools," and also many of the microscopic fungi, including the rusts and smuts. At some stage in their cycle these fungi bear spores on an organ known as a basidium.

Between the main divisions into classes and genera, there are further groups. The most important are orders and families. The genera are gathered into families, the families

into orders, and the orders grouped into classes. A study of the characters of the fungi, and indeed of all living organisms, soon reveals that a natural classification exists, and it is the aim of the systematist working on classification, to mould artificial divisions as far as possible to natural differences. It is not always possible, however, to avoid arbitrary divisions designed to simplify identification of those genera upon which doubt exists as to correct classification.

It only remains to mention a further subdivision, namely the *Myxomycetes*, which are generally considered by the mycologist with the fungi. The majority live on rotten wood or plant remains and are of little interest to plant pathologists.

Chapter Seven

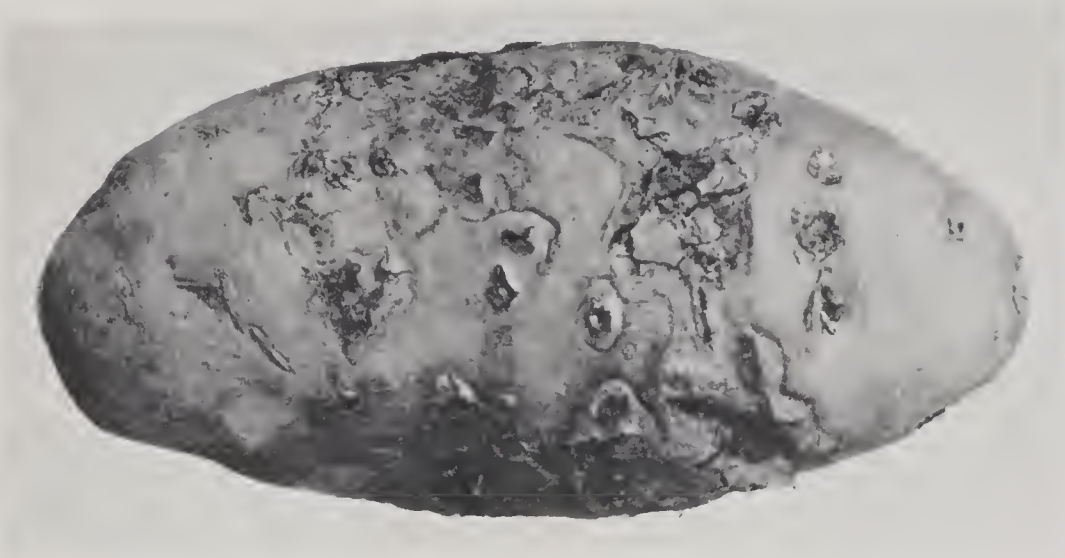
Symptoms of Disease and Principles of Plant Protection

Until the symptoms of a particular ailment or diseased condition appear, no sharp line divides the healthy and the unhealthy state. It is doubtful, therefore, if any satisfactory definition can be given of the term " health," unless, in a negative way, it is defined as that state in which an organism exists when its functions are performed in a normal manner, and its development is not restricted by any adverse condition. What is it that sways the delicate balance of health, determining whether it shall be good or ill ?

The health of man, stock and crops is influenced by three factors—food, environment and disease. There must be a sufficient amount of food, or signs of under-nourishment or starvation are likely to appear. Besides the amount of food, however, the ingredients must be of the right kind, and available in the right proportions. The animal requires a balanced diet of organic foods consisting of carbohydrates, fats and proteins, together with certain salts, vitamins and water.

The plant also needs an adequate and well-balanced " diet," but here it is the simple inorganic nutrients that are required. As we have already seen, these must contain relatively large amounts of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur (especially nitrogen, phosphorus and potassium), and smaller amounts of iron, manganese, boron, copper, zinc and molybdenum. If these elements are not available, or are not present in the right quantity, signs of ill-health may appear. For example, if nitrates are in low supply, young corn may become sickly and turn yellow, but if nitrates are in excess, growth may be too robust, the foliage dark-green, over-succulent and more susceptible to parasitic fungi. When phosphates are deficient, however, the symptoms are different and purple tints appear. Although the more important nutrients (nitrates, phosphates and potash) may be adequate,

PLATE XV

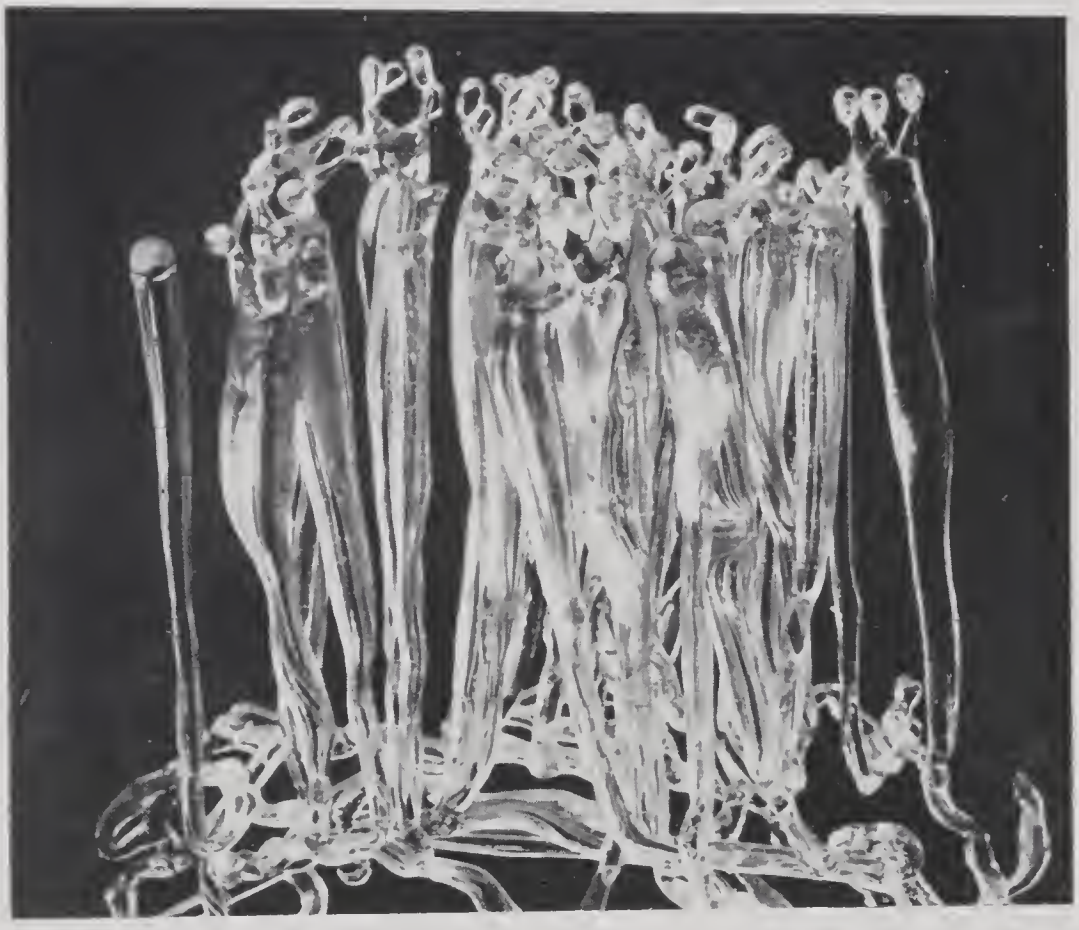


a

b

Powdery Scab of potato (*Spongospora subterranea*): (*a*) Symptoms on the tuber. (*b*) Photomicrograph of the " spore balls " in a section through infected tissue.

PLATE XVI



A glass model of the basidia and basidiospores such as would be seen in a section through the gill of one of the larger *Basidiomycetes*.

PLATE XVII

1 *(Farmer and Stockbreeder photograph)*

2 *(By permission of Miss M. D. Glynne and the Rothamsted Experimental Station)*

1. A badly laid crop of oats near Margaretting, Essex, following the severe storms in August and September, 1946.
2. Lodging in a wheat crop in Norfolk due to the Eysepot fungus (*Cercosporella herpotrichoides*). Ninety per cent. of the straws were infected with the fungus.

PLATE XVIII

a

The Fire disease of tulip (*Botrytis Tulipae*):

(*a*) Primary infection from which spores are spread to neighbouring leaves and flowers.

(*b*) Blemishes produced by secondary infections on a tulip flower.

b

certain trace elements may not be available. For example, on certain soil types, especially thin peaty soils overlying chalk subsoils, the roots may be unable to obtain a sufficient supply of manganese. Of the cereals, oats are especially susceptible to this deficiency: when they are affected, grey or buff-coloured specks or streaks appear on the leaves.

Environment, the aggregate of all the separate conditions that surround the living space of the plant (light, shade, temperature, rainfall, humidity, and the biological, physical and chemical properties of the soil), may influence health in many ways. It should be noted, however, that when frost, cold winds, excessive rain or drought prevail over an extensive area, the harm that is done is not necessarily uniform throughout that area, for other factors may modify their effect. It is seldom possible to alter the conditions that prevail over wide expanses of land, although it is possible to anticipate their effects and to grow varieties better suited to them.

It is with the local environment, the conditions existing in the immediate vicinity of the plant, that the plant pathologist is mainly concerned, for the farmer can modify the physical, chemical and biological nature of the living space in which the roots seek their food. Aeration and drainage can be improved, sour soil sweetened by lime, and deficiencies of organic matter and mineral nutrients made good. When soil conditions are at fault a dual effect is often apparent, for not only are the roots deprived of an adequate supply of food, but the plant becomes more susceptible to certain parasites. From the time the seed is sown until the crop is harvested its health is menaced by parasitic fungi, and once their spores have produced germ tubes and penetrated into the living cells disease may result.

We have already seen that in olden days when plants became diseased they were said to be " blighted," and that in the course of time different kinds of " blight " were recognised and descriptive terms given to them. These names were not standardised, but varied from place to place, and consequently confusion frequently arose. It was not until 1928 that the first attempt was made to standardize the common names of British plant diseases. A list was then compiled by the Plant Pathology Sub-Committee of the British Mycological

Society, and published in March, 1929, in Vol. XIV of the Society's Transactions. The list is now available in book form,* and it is an invaluable reference for those engaged in the study of plant diseases. The Committee state that : " The object in preparing it was to select for each disease a single common name, the use of which it was desired to encourage throughout the British Isles and the Empire. By this means it was hoped to avoid the confusion often caused by the use of more than one common name for the same disease." The scientific names of the parasites responsible for these diseases are also given, and these conform to the International Rules of Botanical Nomenclature. A list of the common names of the parasitic diseases that are mentioned or described in this book is given on p. 153. The identification of plant diseases is based upon an appreciation of the symptoms caused by particular pathogens, and these the plant pathologist learns by practice and experience. Before the impression gained can be confirmed, the causal agent or agents must be found and accurately identified. The following cases afford some typical examples :—

DISEASES OF CLOVER

Case 1. During late autumn, winter and spring, patches of dead or dying plants are seen distributed more or less irregularly in a clover field. The leaves of some plants are " peppered " with brown spots, others are olive-brown and covered with a sparse growth of mycelium. Clover Rot caused by *Sclerotinia Trifoliorum* is suspected. A dead plant is carefully removed and examined for the presence of sclerotia. These are found and the preliminary diagnosis is confirmed.

Case 2. Patches of stunted and sickly-looking plants are observed in a field of red clover. The " disease " appears to have started from a central point, or points, and to have spread outwards in a widening circle. The shoot bases are swollen and puffy in texture and some leaf-stalks are distorted. The leaves are slightly lighter in colour than healthy ones. The presence of Stem Eelworm is suspected, and representative specimens are taken to the laboratory for examination. A small portion of affected tissue is teased apart in a drop of water and mounted on a glass slide. The preparation is examined under the microscope and the presence of the Stem Eelworm (*Anguillulina dipsaci*) confirmed.

DISEASES OF WHEAT

Case 1. Shortly before harvest a field of wheat is examined. Bleached ears with shrivelled grain are scattered throughout the crop. The land is in a high state of fertility but three white-straw crops have been

**List of Common British Plant Diseases* (1944). Cambridge University Press.

taken in succession, and rhizomatous weed grasses are present. Affected plants are readily pulled from the soil, the roots break easily, are greyish in colour, and there is a black discoloration at the base of the stem. The Take-all and Whiteheads disease of wheat and barley is suspected. The material is examined in the laboratory and the runner hyphae of *Ophiobolus graminis* (the soil-inhabiting fungus responsible for Take-all and Whiteheads) are seen lacing the roots.

Case 2. A few bleached ears are seen scattered in a wheat crop. The land is clean, well-farmed and a sound sequence of cropping has been practised. The farmer suspects Take-all. The plants are well rooted, however, and the stem bases are clean. It is suggested that it is more likely that injury has been caused by the Wheat Stem Sawfly (*Cephus pygmaeus*) and the diagnosis is confirmed when the stem is split lengthwise and the maggot disclosed.

Case 3. A crop recorder reports a suspected case of Take-all and Whiteheads, but seeks confirmation and submits specimens. The ears are empty and bleached, the roots rotten, and the bases of the stems brown with pink spore-masses showing. Brown Foot Rot and Ear Blight is suspected, and this is confirmed when the spores of *Fusarium* are identified. It is suggested that the land is probably sour, wet or badly drained, and that these conditions have created an environment well-adapted to the development of *Fusaria* such as *F. culmorum* and *F. avenaceum*. On further inquiry this supposition proves to be correct.

Case 4. Following heavy rains, a rather light crop of wheat is badly laid. The farmer blames the weather. Lodging is not always due to gales and rain, however, or to over-manuring with nitrogenous fertilizers. It can also result from attack by the Eyespot fungus (*Cercosporella herpotrichoides*). The farmer recollects that many individual straws had been falling over to give the crop a straggled appearance before the storms but now the majority of the straws are almost flat with the ground, having bent over sharply at ground level. Careful examination shows that the bases are brown and rotten with the Eyespot fungus.

DISEASES OF SUGAR BEET

Case 1. A field of sugar beet is examined shortly after drilling. The soil, a light loam, is well drained, but weeds are beginning to appear and spurrey is observed. The young seedlings are examined. The stem axes are thin, hard and stringy and have failed to swell in a normal manner. Inquiry discloses that the seed was treated with an approved organo-mercury seed dressing and germination was good. There is no indication of pre-emergence blight or Blackleg. Stringy Root is diagnosed, a disorder due to faulty nutrition, and one prevalent on acid soils. A soil analysis is made, and it is found that lime and phosphates are in low supply.

Case 2. Another field of sugar beet is examined, but the conditions are entirely different. The land is heavy, poorly drained, and owing to an oversight the seed had not been treated with a seed dressing. Cold, wet weather followed drilling and germination was much delayed. When the seedlings are examined it is seen that the stem

axes below soil level are shrivelled and black. The symptoms suggest a form of Blackleg. This may be due to the seed-borne organism *Phoma Betae*, or to certain soil-inhabiting fungi, such as *Pythium*, which prefer wet soils. Subsequent laboratory examination determines that the failure is complex and that both organisms are concerned.

Case 3. Late in the season a sample of sugar beet is received. The central leaves are black and rotten. The farmer says that he has been told that this is a nutritional disorder called Heart and Dry Rot due to a deficiency of available boron in the soil. He seeks confirmation and requires to know when and how to apply borax. He mentions that he farms a heavy silt in a high state of fertility and that sugar beet and mangolds are not grown more frequently than once every four years on the same land. He adds that he wishes to take all reasonable precautions to prevent this trouble recurring as he is now also growing sugar beet for seed purposes.

It is thought that the farmer has been misinformed, as Heart and Dry Rot usually occurs on light alkaline soils or soils that have been made alkaline by the continuous use of alkaline fertilizers. Portions of the dead heart leaves are microscopically examined and the dichotomously-branched conidiophores of the Downy Mildew fungus (*Peronospora Schachtii*) are observed. Inquiries are made and it is found that the crop being grown for seed purposes is heavily infected with Mildew. Spores have been carried by the wind to the root crop which, unwisely, was situated nearby. (The two crops should have been grown as far apart as possible.)

DISEASES OF TOMATOES

Case 1. A grower of tomatoes under glass complains that the plants have started to wilt. Slight recovery occurs at night, but the following day they become limp again. He adds that the soil and air temperature is rather on the low side, and he observes that the wilting starts from the bottom of the plant and works upwards.

These symptoms could be caused by *Verticillium* or *Fusarium*, but *Verticillium* wilt is much more common and, in contrast to *Fusarium*, thrives best at relatively low soil temperatures. Specimens are obtained and it is seen that the root system is relatively clean, but, on splitting the stem lengthwise, it is observed that the woody sap-conducting vessels are stained reddish-brown. The roots, and a portion of the stem, are carefully washed and kept moist in a covered glass dish. When examined microscopically three or four days later the verticillately-branched conidiophores of *Verticillium* are observed.

Case 2. In an old nursery the plants are bearing four or five trusses of fruit but, just as picking is about to begin, the plants begin to wilt. The grower is afraid that the crop will be lost. It is noted that the wilting starts at the top and proceeds downwards. The soil is cold, wet and too compact. A condition of " root rot " is diagnosed, and it is suggested that unfavourable soil conditions have favoured the growth of *Colletotrichum atramentarium*, a soil-inhabiting fungus that causes the roots to decay. When these are examined with a hand lens the black resting bodies of the Black Dot fungus (i.e., *Colletotrichum atramentarium*) are seen.

Although the experienced plant pathologist can frequently diagnose at first sight the cause or causes of a crop failure or a specific plant disease, he is usually unable to do so when the symptoms are indeterminate. Further, it must be remembered that a diseased condition may be complex and, apart from the presence of a parasite, other factors may be concerned.

When the cause of a crop failure cannot be determined immediately, a full record of the case should be compiled. Relevant information should be obtained on the chemical and physical nature of the soil, the standard of fertility, the fertilizers used, the sequence of cropping and the cultural operations that have been carried out. A critical examination of the affected material must then be made, and any signs of nutritional disorders, insect injury, virus infection or the presence of bacteria or fungi recorded. In this connection it must be noted that the presence of bacteria or fungi does not necessarily imply that they are the cause of the condition, for they may be saprophytic. When the plant pathologist is unable to obtain specimens himself, representative samples should be selected for him (including healthy and " diseased " material) and these, carefully packed and labelled, should be dispatched to the laboratory. If unusual features are present, however, it is most desirable that he should conduct his own field investigation and select such material as he requires. For routine diagnoses of the more common complaints, representative samples are usually sufficient, provided a full record of the case is given. It is clear, therefore, that the practising plant pathologist must be well versed in the principles and practice of agricultural and horticultural science, besides having a specialised knowledge of biological subjects.

When a fungus becomes established in living plant tissue it is seldom that the disease it causes can be cured, and consequently means must be taken to limit its spread and its recurrence. It is not well appreciated that, if a primary source of infection can be removed immediately, serious losses may often be averted. This is especially so in horticultural practice. For example, by systematically destroying primary infections of *Botrytis Tulipae*, the Fire disease of tulips can

usually be kept in check. When this is not done, wind and rain quickly scatter spores from diseased plants and an epidemic of Fire results. The roguing of primary infections in this way has been carried out in Holland regularly for many years with complete success.

The failure to destroy logs or dead branches bearing the fructifications of *Stereum purpureum* may lead to severe outbreaks of Silver Leaf in fruit plantations.

Potato Blight is another example that well illustrates the importance of destroying focal centres from which disease originates. Blight usually begins on shoots produced from blighted tubers left in the field the previous autumn, or thrown out when the clamp is opened. The neglected sites of potato clamps are plague spots, for it is from infected self-sown sets that the disease often spreads. Too often, when the clamp is opened, diseased tubers are thrown out and left lying about or, alternatively, they are dumped on some convenient site, very often close to a potato field, and left to produce plants that harbour not only Blight but virus diseases as well.

Although a disease can seldom be cured once infection has taken place, it is sometimes possible to retard its progress and save a crop that would otherwise fail. For example, when the Verticillium Wilt fungus attacks tomatoes, it is possible, as a temporary expedient, to raise the air and soil temperatures so that these are unfavourable for the development of the parasite. This palliative, however, would be of no avail if the wilt was induced by root-rot organisms. To save the crop in these circumstances it would be necessary to induce new root growth from the bases of the stems by the application of a good layer of peat.

Prevention is better than cure, and the various principles underlying the prevention of the common crop diseases must now be described. As we have already seen, the spores of parasitic fungi may be everywhere—on the seed, in the soil, and in the air. By what means are plants to be protected from them? Diseases that are due to the use of contaminated or infected seed can usually be prevented by methods of seed disinfection, and those that arise from soil-inhabiting fungi by modifying the rotation, or growing varieties resistant to

attack. It is more difficult, however, to obtain an economic control of diseases brought about by airborne spores, for their prevention involves the application of fungicidal sprays, unless immune or highly resistant varieties can be grown. Such sprays are used extensively in horticulture, but in farming practice they are limited to certain crops.

Chapter Eight

Seed Treatment—Modern Methods

It has been mentioned already that Mathieu Tillet, in 1752, discovered the infective nature of the black, dust-like powder in smutted ears of wheat, and that Bénédict Prévost, in 1807, showed that this dust consisted of the spores of a microscopic fungus. Prévost, continuing his observations, noticed that when these spores were placed in drops of water they germinated and produced minute tubes, but that these did not form when he added traces of copper sulphate. Schulthuss had suggested many years before (in 1761) that instead of "brining" wheat it should be steeped in a solution of copper sulphate, and this treatment had been used by some with success.

Here, then, was the explanation of its efficiency—Covered Smut of wheat was a seed-borne disease, and copper sulphate prevented the spores on the surface of the grain from germinating. Thus, the scientific principle underlying disinfection was established long before the terms "germs" and "microbes" were in common use. Theory is one thing and practice another, and it was not until 1859, when Kühn published his work on cereal seed treatment, that the use of copper sulphate came into any prominence. One recipe for treating wheat in this way is as follows :—The grain is placed in a heap on a clean barn floor and is sprinkled or sprayed uniformly with a solution of 2½ lb. of copper sulphate dissolved in 10 gal. of water. Rather more than one but less than two gallons of the solution is required for every four Imperial bushels of seed. While it is being sprinkled, the seed is mixed thoroughly by continuous shovelling over, so that each grain is thoroughly moistened with a thin film of the solution. It is then raked out in a thin layer to dry as rapidly as possible, and when dry it is sown. The treatment has several disadvantages, however, for it frequently causes injury to the grain, especially if it is not dried quickly and sown within

PLATE XIX

(By permission of the Ministry of Agriculture and Fisheries)

1. A power-driven machine acquired by the Cambridge University Farm in 1925, for disinfecting seed wheat.

(By permission of the Ministry of Agriculture and Fisheries)

2. A modern type of continuous-feed, power-driven machine.

PLATE XX

(By permission of the Ministry of Agriculture and Fisheries)

1. Machinery installed for disinfecting seed corn at the National Institute of Agricultural Botany.

(By permission of the Ministry of Agriculture and Fisheries)

2. Disinfecting corn on the barn floor—a primitive method that is not recommended.

PLATE XXI

A simple machine for disinfecting small quantities of grain.

(By permission of the Ministry of Agriculture and Fisheries)

PLATE XXII

1. The type of abnormal germination that may result from storing treated grain in damp and unsuitable conditions.

2. Leaf Stripe of barley (*Pyrenophora graminea* = *Helminthosporium gramineum*).

3. Leaf Blotch of barley (*Rhynchosporium Secalis*).

two or three days; moreover, it is not a suitable treatment for oats or barley as it impairs the vitality of these grains.

The next advance in the development of seed disinfectants was the use of formaldehyde. This chemical was discovered by Hofmann in 1867, but it was not until 1895 that Geuther used it as a seed disinfectant. Formaldehyde is a gas and is sold as an approximately 40 per cent. solution in water, under the name of formalin. The dilution required is 1 pint of formalin to 40 gal. of water. As in the copper sulphate treatment the seed wheat is uniformly and carefully sprinkled or sprayed with the solution and constantly turned during the process. From 1 to 2 gal. of solution is required to moisten 4 Imperial bushels, care being taken to see that pools do not form under the heap. After sprinkling and shovelling, the grain is made into a heap, covered with sacks previously wetted with the solution, and left undisturbed for four hours, during which time the formaldehyde completes the disinfecting process. It is then raked out into a thin layer and dried as rapidly as possible. It should then be sown within two days at most.

This new disinfectant did not readily displace the old bluestone treatment, however, and it was not until the early twenties of this century that it was extensively used. This is surprising for, if correctly applied, it is not only an effective treatment for Covered Smut of wheat, but also Covered Smut of barley and the Oat Smuts. Copper sulphate is suitable for wheat only, but formalin can be used for wheat, barley, oats and rye.

There are several disadvantages in using liquids for seed disinfection. The moistening of the grain is a laborious and troublesome operation, and germination is adversely affected unless the grain is dried quickly and sown as soon as possible. It is not surprising, therefore, that the use of powders was suggested. In 1902, Von Tubeuf tried " candying " the grain with various substances, one of which was a precipitated copper-carbonate powder, and with this he obtained promising results.

It was not until 1917, however, when Darnell Smith in Australia advocated the use of a basic copper-carbonate powder for dressing seed wheat, that dry disinfection with

dusts received any stimulus. The treatment was then used in the United States of America with some success, for it was estimated that one-tenth of the total wheat acreage in 1925 was so treated, with a net gain of at least five million bushels. From 1923 onwards, experiments with copper carbonate were made in England and Wales and, on the whole, the results were satisfactory, provided the seed was not too heavily contaminated with smut spores. The treatment was simple and was done by churning the seed and powder together in a revolving barrel or drum, the powder being used at the rate of 2 oz. per bushel of grain. Nevertheless, it was not readily accepted, and most farmers continued to use copper sulphate or formalin.

It is of interest to note, however, that a power-driven machine with a continuous feed designed for disinfecting wheat in this way was installed in 1925 on the University Farm, Cambridge, and was used for treating pedigree seed stocks before these were dispatched from the farm. The introduction of this machine, and its subsequent use, is probably the first instance in Britain of such a practice. This development, together with experimental work of a similar nature that was being done at the time by the seeds firm of Messrs. Gartons, Ltd., represented a practical endeavour to limit the spread of disease by disinfecting seed stocks before they were received by the farmer. At this time it was customary to treat only seed wheat, and, as ready-made machines were not available for treating grain in this new way, farmers were disinclined to improvise their own, and the method was not readily accepted.

Before 1930 partial or complete failures were very frequent in oat and barley crops and caused much concern. Spring oats especially seemed to depend upon the whims of providence (as in a sense they did), but barleys too were often very disappointing. The causes of these recurring oat failures were the ravages of the Frit Fly (*Oscinella frit*) and a disease known as Leaf Spot (or Stripe as it was sometimes called), a seed-borne disease caused by the fungus *Helminthosporium Avenae*. Fortunately, entomologists had studied the life history of *Oscinella frit* very carefully, and had demonstrated that losses could be avoided by sowing spring oats early ; but nothing

(so it seemed) could be done to prevent the damage caused by the Leaf Spot fungus. Indeed, many thought that a few odd spots or stripes on oat leaves were of little or no account, but unfortunately they overlooked, or were unacquainted with, the more sinister phase of this disease, namely, pre-emergence blight (i.e., the death of the young seedlings before they speared through the soil).

The importance of this phase is well illustrated by some observations made on the Cambridge University Farm in 1925. A detailed field analysis was made of a high-germinating sample of Black Supreme seed oat known to be infected with the fungus causing Leaf Spot. Of the seedlings that appeared above ground 52 per cent. showed symptoms of Leaf Spot, but only 5 per cent. of these died—not a very serious mortality. Below ground, however, a heavy mortality had occurred : of the total seed sown, 56 per cent. was killed before emergence. At that time failures of this kind were usually attributed to wireworms, cold winds, or frost injury, and the real cause was not appreciated—and when it was appreciated little could be done to prevent losses. A change of seed could be suggested in the hope that it would be free from disease, but with little prospect of it being so, for the majority of samples were infected. Seed disinfection with formalin was of little or no avail, copper sulphate could not be used as it markedly reduced germination, and the new treatment of dusting with copper carbonate was ineffective. A detailed study of the disease was published in 1930 by O'Brien and Prentice, who drew attention to its prevalence and importance in Scotland.

As barley was also affected by a similar disease, and did not respond to treatment with any of the known seed disinfectants, it will be realised that the time was ripe for the introduction of more effective fungicides. The need was met, and new seed disinfectants known as organo-mercury seed dressings were evolved. Not only did they give an excellent control of the Stripe diseases, but they also prevented Covered Smut of wheat, Covered Smut of barley and the Oat Smuts. The new dressings were in powder form and the treatment was carried out in the same way as that adopted when using copper carbonate.

Now that a really effective dry form of seed dressing had been discovered, increasing interest was taken in the disinfection of cereal seed, and machines for treating it in this new way became available. Some were simple barrels or churns fixed so that they could be rotated by turning a handle, and with these it was possible to dress about twelve bushels an hour. Others were more elaborate and capable of treating larger quantities more quickly. Some models were designed with a continuous feed ; these were power-driven and dressed from 50-80 bushels per hour. Machines of this type were used by farmers growing large acreages, or by seed merchants. The latter, realising the great importance of the new treatment in preventing disease, installed machinery for the purpose, and for a small charge contracted to treat any seed corn that they supplied. To-day there are hundreds of seed merchants so equipped, and this marks a notable advance in the romantic history of disease control.

What was the origin of these seed dressings, which are so familiar to-day ? The first record of organo-mercury compounds as a possible means of preventing cereal seed-borne diseases was made by Riehm in 1913, but their subsequent development was largely associated with research work carried out by commercial firms, and it is not customary for discoveries of this nature to be communicated to the scientific press. Contributions were made, however, from other sources, by Gassner and Esdorn in Germany in 1923, and by Dillon Weston and Booer in England in 1935.

What is the nature of these proprietary organo-mercury seed dressings ? Their composition varies with the particular commercial product, but the main ingredients are very finely-divided inert mineral carriers or fillers, with which are mixed or impregnated small quantities of one or more organo-mercury compounds ; an anti-dust of an oily nature and a dye are also usually added. In certain products that have been widely used approximately 98-99 per cent. of the seed dressing consisted of the inert filler, and 1-2 per cent. only—and sometimes less—of the mercury compound. It would serve no useful purpose here, however, to describe the particular types of ingredients used in the compounding of these disinfectants, and for further information the reader is referred to *The*

*Scientific Principles of Plant Protection.** As there are now several brands of organo-mercury seed dressings available and their composition is not identical, it is clear that the question arises as to which is the best product to use. These new seed dressings are competitive proprietary articles, and no organisation yet exists in this country whereby such materials can be

GROUP
NO.
MINISTRY OF AGRICULTURE AND FISHERIES
DEPARTMENT OF AGRICULTURE FOR SCOTLAND
This product is guaranteed by
to conform to a standard approved by the Ministry and the Department for preparations to be used for the purposes indicated on this container and is included in the list of approved insecticides and fungicides under the scheme for the approval of proprietary products for the control of plant pests and diseases.

Fig. 3. The mark of an approved product.
(*By permission of the Ministry of Agriculture & Fisheries*)

tested officially for the results to be published ; nevertheless, many independent trials have been made and the efficiency of the better-known dressings well established.

To safeguard the farmer against "quack" remedies and products of dubious efficacy, the Ministry of Agriculture and Fisheries and the Department of Agriculture for Scotland have

*Martin, H. (1940). *The Scientific Principles of Plant Protection*, 385 pp. London, Edward Arnold.

instituted a voluntary scheme for the approval of certain insecticides and fungicides (marketed under proprietary brand names) for the control of plant pests and diseases. The way in which this scheme is operated is explained in the October, 1943, issue of *Agriculture*, the Journal of the Ministry of Agriculture. Approved insecticides and fungicides bear the name of the article and a diamond-shaped approval mark, as shown in figure 3. The organo-mercury seed dressings are included in this scheme in Group F.

It cannot be emphasised too strongly that, if healthy cereal crops are to be grown, seed disinfection with an approved organo-mercury dressing is an essential practice—a valuable insurance against losses caused by seed-borne diseases. It must be appreciated, of course, that the control obtained is sometimes not complete and disease appears. The intensity of infection depends upon several factors, the dressing used (for some are slightly better than others), the method of application and the climatic conditions prevailing at and after sowing. The way in which the dressing is applied is most important. Some farmers attempt to carry out the mixing in a sack, or by spreading the grain on a barn floor, scattering the powder over it and turning several times with a shovel. *These methods are not recommended*, because they lead to inequalities in the dosage rate, some seeds receiving too much and others too little. This may result in poor germination and less effective disease control. Further, as these powders are poisonous, there is danger to the health of the operator.

The most effective way of treating seed corn is to use a machine of the barrel or churn type, the mixing being done by rotation. Inexpensive machines of this kind can be purchased, or a home-made one easily constructed from a barrel or drum mounted so that it can be rotated by turning a handle. There are other types of machine, however, in which the mixing is done not by rotation, but by gravity. In one such machine, known as the gravity seed dresser, the grain and powder are mixed by falling over a series of cones contained in a hollow cylinder. These machines are inexpensive, and the treatment a quick one, but the mixing is not so thorough as that obtained by churning the seed and powder together. It must be

remembered that these dressings are poisonous and consequently care must be exercised when using them. The makers state that it is advisable to avoid inhaling the dust, and that the nose and mouth should be protected with a cloth or respirator. Further, as they have a vesicant action, they should not be handled with wet or moist hands or allowed to come into contact with wounds or broken skin. They state, too, that after the treatment has been done, any dressing remaining on the hands should be removed by rinsing thoroughly.

It is sometimes asked whether there is any risk of these dressings impairing the vitality of the grain. A characteristic injury can be produced by excessive overdoses, and when the treated grain is stored in damp and unsuitable conditions. Provided it shows relatively high initial germination, is of sound physical condition and is superficially dry when treated with these powders, no immediate injury to the grain is likely to result. If such seed has to be stored, it is unlikely that any significant loss of germination capacity will occur for several months, provided it is kept under dry, cool conditions with adequate ventilation. Seed treated with these dressings should not be used for feeding purposes, and bags or sacks which have contained such seed should be shaken out or washed before being used for carrying fodder. Samples of treated grain must *not* be used for milling purposes or human consumption.

Unfortunately there is an impression among many farmers that the organo-mercury seed disinfectants are a " cure " for all the ills to which corn is subject ; not infrequently complaints are made that after corn has been dressed with these products disease has appeared in the crop. This is often so, for they cannot ward off Rust, Mildew and Take-all, neither can they prevent Loose Smut in wheat and barley. It must be realised that the only diseases that are prevented are those due to harmful organisms on the surface of the grain. For example, of the diseases from which barley suffers, two are Leaf Stripe and Leaf Blotch. Seed disinfection will control Leaf Stripe, but it will not prevent Leaf Blotch, as it is not a seed-borne disease.

It is Loose Smut of wheat, and more rarely Loose Smut of

barley, however, that perplex the farmer, for he knows that they are both seed-borne diseases and yet he obtains no control of them. Covered Smut of wheat, Covered Smut of barley and the oat Smuts are due to spores which contaminate the surface of the grain, and these are killed when a suitable disinfectant is applied. With Loose Smut in wheat and barley, on the other hand, the grain is infected internally, the fungus spawn being deeply embedded within it. It is clear, therefore, that the external application of a disinfectant, in any of the ways already noted, would not prevent this type of disease. The problem of control is difficult because it is necessary to kill the spawn within the grain without injuring the vitality of the embryo. Towards the latter part of the nineteenth century Jens Jensen discovered a way of doing this. The method devised was to steep the seed in warm water at a temperature just high enough to kill the fungus without impairing the germination of the grain.

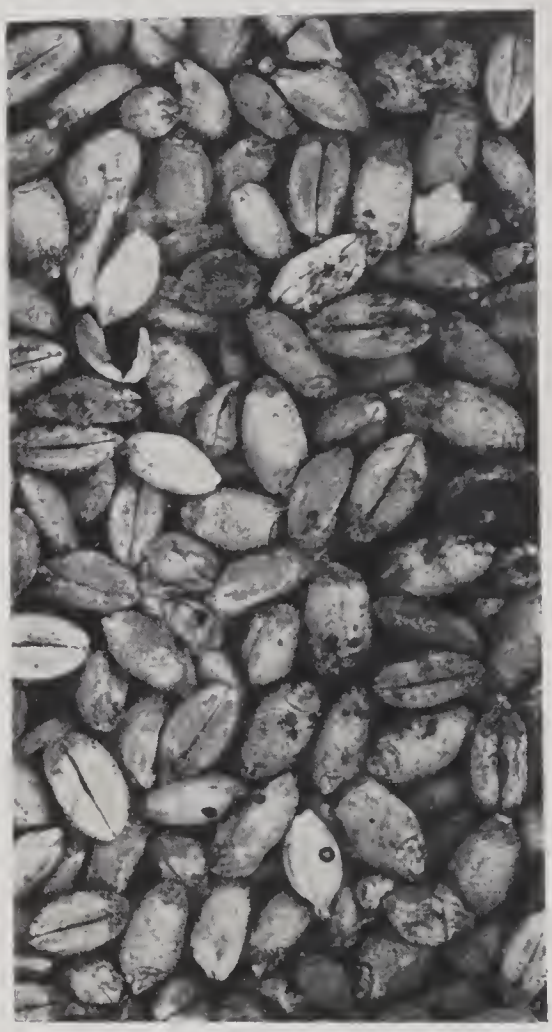
Unfortunately this treatment involves much risk, for if the temperature is slightly too high the grain is killed ; nevertheless, under skilled supervision, it is successfully practised in some countries. It is not usually recommended in Britain on account of the risks involved, for adequate apparatus and facilities are not available on the average farm. Further, relatively little information is available on the reaction of different varieties, or on the injurious effects that may arise if grain treated in this way is incorrectly dried and stored. Fortunately these diseases are of small consequence in Britain, and, except in a few varieties (e.g., Hybrid 27 = Vilmorin 27), cause very little loss. In countries where these diseases are of economic importance, special machines have been designed for carrying out the process, and in the United States of America, and in some Continental countries, co-operative or community plants have been introduced.

A novel modification of Jensen's treatment, but one with an application limited to hot climates, was devised in 1934 by Jai Chand Luthra* in India. Samples of smutted wheat were pre-soaked in water at ordinary temperature for 4 hours, i.e., from 8 a.m. to 12 noon ; they were then taken out

*Luthra, Jai Chand (1934). Some Experiments on the Control of Loose Smut, *Ustilago Tritici* (Pers.) Jens. of wheat. *Indian J. Agric. Sci.*, **4**, (1).

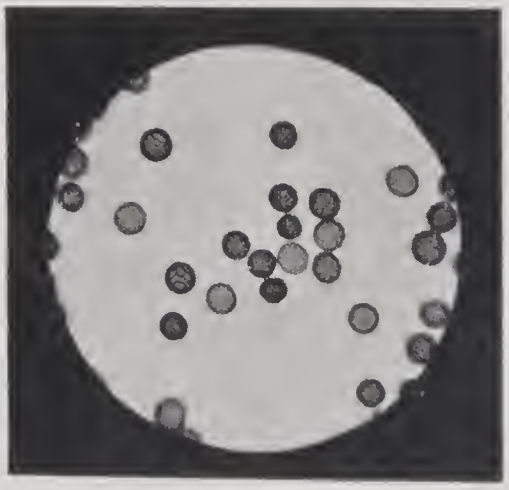
PLATE XXIII

a



b

c



d

Bunt of wheat (*Tilletia caries*): (*a*) Infected ear; (*b*) Grain contaminated with spores liberated during threshing; (*c*) Bunt balls; (*d*) Photomicrograph of Bunt spores.

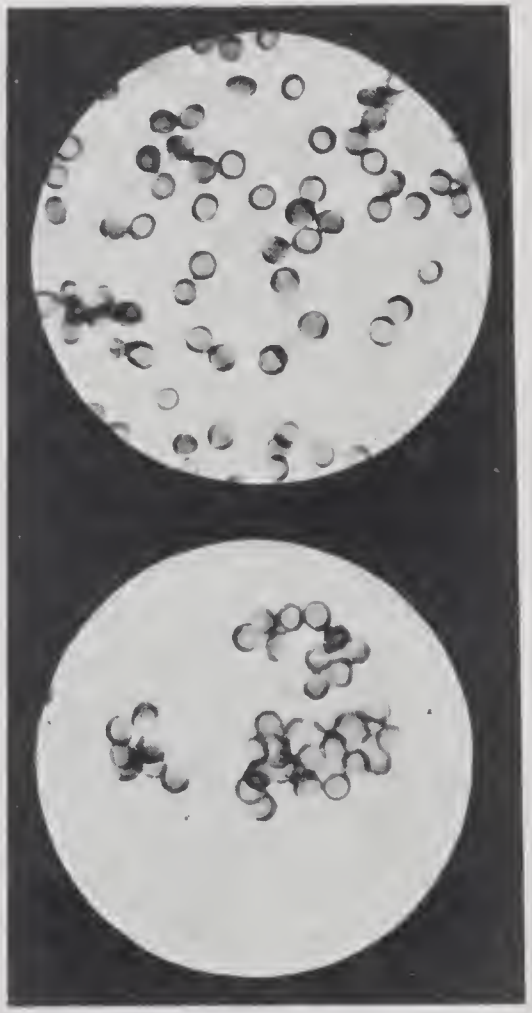
PLATE XXIV

1. Ears of wheat infected with Loose Smut (*Ustilago Tritici*).

2. Oat Smuts (*Ustilago* spp.).

PLATE XXV

1. Ears of barley infected with Covered Smut (*Ustilago Hordei*).



2. Photomicrographs of the spores of :
(*a*) (above) *U. Hordei.*
(*b*) (below) *U. nuda.*

3. Ears of barley infected with Loose Smut (*Ustilago nuda*).

PLATE XXVI

Leaf Stripe of barley (*Pyrenophora graminea* = *Helminthosporium gramineum*):

(*a*) Seedling symptoms.

(*b*) Symptoms on the mature leaf.

a

b

and exposed to the sun from 12 noon till 4 p.m. The crop raised from the treated seed was quite free from the disease, but the untreated crop had as much as 14 per cent. of smutted ears. There are many variations of Jensen's original treatment, and the principle has been applied successfully for the control not only of Loose Smut of wheat, but also of other seed-borne diseases, and bulbs, corms, rhizomes, etc., are sometimes treated in this way to control certain eelworm diseases.

It might be thought that there is now no further need for investigating problems related to seed disinfection, but this is not so and research still continues. An interesting trend was a suggestion (which in some instances was put into practice) that "plant hormones" should be incorporated with seed disinfectants, with the object of stimulating root growth. Experiments in Britain afforded little or no evidence that yields were materially increased by the use of seed dressings of this type, and research in Canada and the United States indicated that, although such "growth hormones" are potentially capable of inducing physiological activity when applied in seed dressings, they do so in practice only under conditions that occur very rarely. It is not unlikely, however, that some of the steeps used in earlier days contained such substances, and that these may have produced beneficial results—but this is mere speculation.

To what extent is seed disinfection practised in Britain? It is probable that 75 per cent. of seed wheat is treated, but not much more than a third of the oats—except in Scotland, where the treatment is general. The figure for seed barley is probably much the same as for oats. Very little rye is treated, although it is susceptible to two smut diseases. Much saving could be effected if cereal seed disinfection were universally practised. As long ago as 1771 Peters,* in *Winter Riches*, says: "Shall I stand alone convicted by all mankind, stand a culprit before my great superiors, when I affirm the great omission, in not reminding the farmer, that it is absolutely as necessary for him to take the same precaution, care, and assiduity, through every species of grain he commits to the benevolent earth, as to wheat," and concludes: "Is it because they are not of equal value—too vague a word to answer? Let me therefore

*Peters, M. (1771). *Winter Riches*. London. Flexney.

recommend that duty (you owe to yourselves) as much to one, as the other ; they are all fed with the same food, and nourished in the same earthy bowels . . ."

From what has been said the reader may have assumed that chemical seed disinfection is restricted to cereal seed only, but this is not so, as we shall see later.

Chapter Nine

Diseases Caused by Seed-borne Fungi—Cereals

Crop yields depend to a large extent upon the quality of the seed sown, but apart from any consideration as to the choice of the variety, its trueness to type, freedom from weed impurities, or germination capacity, the seed may be contaminated or infected with disease organisms. Losses arising from some seed-borne diseases ought not to occur, for they can be prevented by chemical or thermal methods of seed disinfection. Before these diseases are considered, however, it is necessary to emphasise again the difference between *contaminated* and *infected* seed, for these terms are not interchangeable, and their significance is not always appreciated. Contaminated seed bears upon its surface ungerminated spores ; infected seed is penetrated by mycelium, and this may be superficial or deep. When the seed is contaminated by spores, or slightly infected with superficial mycelium, the fungus can usually be killed by chemical methods of seed disinfection, but this is of no avail when penetration is deep. In these circumstances the only effective remedy is thermal disinfection, but this is a risky process, and expert advice should always be sought before applying it.

An outline can now be given of the symptoms of the common seed-borne diseases of farm crops and the appropriate measures of seed disinfection.

WHEAT

Bunt, Covered or Stinking Smut (*Tilletia caries*). In the threshing machine the seed is contaminated by spores. When the seed is sown the spores germinate and the young shoot is infected. The mycelium finds its way into the tip of the young shoot where it keeps pace with the growing point, but noticeable symptoms are not seen until flowering time. At this stage the ears are a darker green, and the chaffy scales are spread wider apart than those in healthy ears. Instead of

grains developing, " bunt balls " containing a black mass of powdery spores are formed. A few " bunt balls " break open before the crop is harvested, but the majority remain intact until threshing time.

Control Measures. Sprinkling with, or steeping seed wheat in, a solution of copper sulphate (bluestone) will prevent Bunt, as will a solution of formalin suitably applied. The strengths of the solutions required, the way of applying them, and the disadvantages of these methods have already been described (Ch. 8).

The modern treatment, however, is by dry-dusting seed wheat with an approved organo-mercurial seed dressing. If the grain is not well-conditioned and is slightly damp, it should not be dressed in advance and stored, but should be treated immediately before sowing. These dressings contain a *poison*, and consequently they should be used as directed by the manufacturer, and the appropriate precautions taken.

Loose Smut of Wheat (*Ustilago Tritici*). At flowering time the spores are blown away by the wind from smutted plants and some fall on to the flowers of healthy ears. If conditions are suitable they germinate, and produce mycelium that enters the developing grain. There is no visible effect of this on the seed, however, and it ripens in the normal way. Nevertheless, although the seed appears to be healthy, it is infected internally, and the mycelium is deeply embedded in the tissues. When infected seed is sown the dormant fungus re-awakens and grows up with the growing points of the main and lateral shoots. This is not discernible, however, and the disease symptoms are not observed until the flowering stage, when the developing grains are converted into a loose, black mass of powdery spores that are soon blown away. It is clear, therefore, that chemical seed disinfection will not prevent Loose Smut.

Control Measures. The only effective remedy is thermal seed disinfection, but the disease can be avoided by careful selection of seed corn from crops that do not show the disease. For those who are willing to accept the risk that thermal seed treatment may involve, the following guidance is given :— " Those who cannot obtain clean seed and who wish to try the hot water treatment, should put their seed grain into a sack,

incompletely filled to allow for swelling, and place the sack in a vessel of cold water so that it is just covered. The sack should be raised and lowered several times to make sure that the water reaches all the contents, and then left to stand for 4 hours. After standing, the sack is lifted out, allowed to drain a few minutes, and then submerged for 10 minutes in a tank of warm water. During this period the warm water *must* be kept between 52°C. and 54°C., and for this a thermometer is essential. If below 52°C. (125°F.), the mycelium will not be killed ; if above 54° C. (129°F.), germination of the grain will be affected. When the cold sack is plunged into the warm water, the temperature of the latter will, of course, drop, and this must be adjusted by adding boiling water. By moving the sack about from time to time uniform heating will be facilitated. After 10 minutes the contents of the sack is spread in a thin layer on a clean floor and allowed to dry. It should be sown when dry."*

BARLEY

Covered Smut (*Ustilago Hordei*). The life cycle of the organism causing this disease is very similar to that of the Bunt fungus. Contamination of the seed occurs in the threshing machine. When sown, spores and seed germinate together and the young shoot becomes infected. Noticeable symptoms are not seen, however, until the black ears emerge from the leaf sheaths. The affected " grains " remain more or less intact and the spore masses are not readily blown away.

Control Measures. The formalin treatment is an effective remedy, but copper sulphate should *not* be used as there is a serious risk of impairing the germination. The modern method is to use one of the approved organo-mercury seed dressings, for these, besides preventing Covered Smut, are also effective in preventing Leaf Stripe.

Loose Smut (*Ustilago nuda*). When the smutted ears emerge from the leaf sheaths the spore masses do not remain intact but are blown away by the wind, and eventually bare stalks are left. The spores released in this way germinate on the stigmas of healthy flowers, and the mycelium penetrates

*Bulletin No. 129 (1945). *Cereal Diseases*, p. 10. The Ministry of Agriculture and Fisheries, London.

deeply into the developing grain, as with the fungus causing Loose Smut of wheat. The seed, therefore, is infected internally, and consequently chemical methods of seed disinfection are useless.

Control Measures. Loose Smut is of minor importance in Britain, and usually can be avoided by obtaining seed stocks from barley crops in which the disease has not been present.

The only effective remedy is thermal seed disinfection, and the procedure is somewhat similar to that described for the prevention of Loose Smut of wheat. The grain is pre-soaked for 4 hours, and then steeped for 5 minutes in water at 49°C. (120°F.). It is then placed for 10 minutes in water at or a little above 51°C. (124°F.), but the temperature should not be allowed to rise to 54·5°C. (130°F.), or the grain will be injured. It should then be spread out to dry, and when dry sown.

Leaf Stripe (*Helminthosporium gramineum*).* The mycelium infects the husks or seed coat, but does not penetrate deeply. When infected seed is sown the dormant fungus re-awakens and attacks the young shoot ; if weather conditions are favourable for the growth of the fungus, the seedling is killed before it emerges. This phase is called *pre-emergence blight*, and is responsible for thin stands. The affected seedlings that survive are unhealthy, and show narrow, longitudinal, brown stripes on their leaves.

The course of the disease is progressive ; the first sheath (coleoptile) contracts the disease from the seed coat, the first leaf is infected by contact with the diseased inner surface of the sheath, the second leaf from contact with the enclosing sheath of the first leaf, and so on. Finally the ears become infected by being pressed against the diseased leaf sheaths outside them. Thus, many ears fail to develop normally and are partially or completely " blind," a condition resulting in poorly-filled ears and a higher proportion of tail corn. Leaf Stripe, therefore, reduces both yield and quality.

Control Measures. Copper-sulphate solution gives a very slight control of Leaf Stripe but it should *not* be used, as the germination may be very considerably impaired. Formalin gives little or no control.

*The perfect stage of the fungus is *Pyrenophora graminea* Ito & Kuribay.

The only practical and effective remedy is by treatment with an approved organo-mercury seed dressing.

Net Blotch of Barley (*Helminthosporium teres*).* Net Blotch is a seed-borne disease closely related to Leaf Stripe, but it is less important. It is usually only the first leaf that shows a brown, narrow stripe. The spores produced on this infect the other leaves, and cause irregular, brown blotches consisting of a network of criss-crossed brown lines.

Control Measures. As for Leaf Stripe of barley.

OATS

Covered Smut (*Ustilago Kolleri*) and Loose Smut (*Ustilago Avenae*).† These two smuts cause confusion to farmer and student alike, and they find it difficult to tell them apart. This is understandable, for it is often impossible to determine the difference between them—even when the spores are examined under the microscope. In both, contamination of the grain can take place in the threshing machine, but apart from this, there is evidence that spores are also trapped between the chaffy scales at flowering time and cause infection. There is no evidence, however, that these spores infect the grain *internally* as do the fungi responsible for Loose Smut of wheat and Loose Smut of barley, and the practical proof of this is that the Smut diseases of oats can be prevented by chemical methods of seed disinfection.

Control Measures. The formalin treatment is a most effective remedy for the prevention of Smut, but it gives no control of Leaf Spot of oats. It is largely for this reason that the formalin treatment has now been superseded by the use of organo-mercury seed dressings.

Leaf Spot and Seedling Blight of Oats (*Helminthosporium Avenae*).‡ This disease is very similar to the Stripe disease of barley. The surface of the seed may be contaminated by spores, or mycelium may be present in the husks and seed coat. The mycelium, however, does not penetrate deeply. Affected seedlings may be killed before emergence (i.e., pre-emergence

*The perfect stage of this fungus is *Pyrenophora teres* Drechsl.

† " The spores of *U. Kolleri* are usually smooth ; those of *U. Avenae* usually echinulate (i.e., bearing small spines). It may be doubted whether these two smuts deserve to be regarded as more than varieties of the same species." *Cereal Diseases*, Bull. No. 129, Ministry of Agriculture and Fisheries, London.

‡The perfect stage of this fungus is *Pyrenophora Avenae* Ito & Kuribay.

blight), or pierce through the soil in a weakened state ; but if conditions are favourable for the fungus many of them will not survive and a thin stand will result. The effect on the seedlings (seedling blight), is sometimes confused with wind or frost injury. Unlike Leaf Stripe of barley, Leaf Spot of oats is not steadily progressive, and, for a period after tillering, the disease remains quiescent. Later, usually in June and July, a secondary phase develops and brown spots appear on the maturing leaves ; from these diseased areas arise the spores that later infect the grain.

Control Measures. As for Leaf Stripe of barley.

RYE

Stripe Smut of Rye (*Urocystis occulta*). Stripe Smut of rye is characterised by the appearance on the stems and leaves of silvery-black streaks containing smut spores. Infection frequently results in distortion of the affected parts, and the ear often fails to develop normally, and is sometimes smutted. The disease is rare in Britain, but in recent years it has been observed on several occasions in the eastern part of England. Stripe Smut is seed-borne and the grain is contaminated in the threshing machine, but the disease can also be contracted from spores in the soil.

Control Measures. Stripe Smut can be prevented by chemical methods of seed disinfection, and by a suitable sequence of cropping in which rye does not occur too frequently in the rotation.

PLATE XXVII

a

b

Leaf Spot and Seedling Blight of oats (*Pyrenophora Avena* = *Helminthosporium Avenae*):
(*a*) Infected seedlings, some showing " pre-emergence blight."
(*b*) Photomicrograph of spores.

PLATE XXVIII

(By permission of Dr. D. Walters Davies and the University College of Wales, Aberystwyth)

The effect of treating seed oats with an organo-mercury dust on a farm in Cardiganshire. Left side sown with treated seed; right side, untreated.

PLATE XXIX

a

b

Stripe Smut of rye (*Urocystis occulta*) : (*a*) Infected tillers.
(*b*) Photomicrograph of spores.

PLATE XXX

a

b

Peas plated out on a nutrient medium in petri dishes:
(*a*) Abundant development of moulds on untreated seed.
(*b*) Freedom from mould growth on seeds previously treated with an organo-mercury seed disinfectant.

PLATE XXXI

1

2

1. Sugar beet seedlings with Black Leg (*Phoma Betae*).

2. Sugar beet seedlings attacked by the Pigmy Mangold Beetle (*Atomaria linearis*).

PLATE XXXII

a

b

Celery Leaf Spot (*Septoria Apii-graveolentis*). (*a*) Seedling infection. (*b*) Symptoms on an older leaf.

Chapter Ten

Diseases Caused by Seed-borne Fungi—Other Farm Crops

Modern seed dressings of the organo-mercury type, besides killing exposed spores and mycelium on the surface of the grain, also exert a protective action, and the term *seed protectant* is sometimes used to describe them. The terms *seed disinfectant* and *seed protectant*, however, are not necessarily synonymous. A seed disinfectant such as formalin has an immediate but no lasting value as it cannot confer subsequent protection on the seed. A bunted sample of wheat treated with formalin, and sown immediately it is dry, produces a crop free from Covered Smut, but if the sample becomes re-contaminated with bunt spores after it is dry, as might well happen, the disease is not prevented. With a modern seed dressing subsequent re-contamination is immaterial as a protective layer of fungicidal dust covers the surface of the seed.

Formalin, therefore, is a seed disinfectant with a very limited protective action, and cannot correctly be described as a seed protectant. It confers immunity from some of the organisms present on the seed but it cannot prevent disease arising if the seed becomes re-contaminated ; neither can it retard invasion by harmful organisms that may surround the seed when it is sown. When conditions for germination are favourable, seedlings may temporarily escape the potential disease organisms that surround them, but when conditions are adverse, infection may result and a condition of *pre-emergence* or *seedling blight* ensue. This is well exemplified in the germination of green peas.

GREEN PEAS. This crop has become of increasing economic importance in the past twenty years, and its successful cultivation is often much influenced by climatic and soil conditions, especially during the first few weeks after sowing. If adverse weather prevails poor germination results, although the seed

sown may have been viable and not necessarily diseased. Failures of this kind are usually associated with the rotting of ungerminated seed in the soil, although seed from the same bulk sample when sown under more favourable conditions germinates well and produces a satisfactory crop. This premature dying of seedling plants is associated with various fungi, notably *Ascochyta Pisi*, and various species of *Pythium* and *Fusarium*. *Ascochyta* is a seed-borne fungus, but *Fusarium*, although sometimes seed-borne, is normally a soil-inhabiting fungus.

It is not necessary here, however, to consider the relative pathogenicity of these and other organisms that cause poor plant establishment, but to indicate how better stands may be established and the rotting of the seed in the soil decreased. Experiments have shown that seed treatment with a reliable organo-mercury seed dressing, for sowings earlier than March, is likely to result in an increased stand and yield of marketable pods. For sowings later than this there is no definite evidence that the treatment is an advantage. The beneficial effect of seed treatment, however, does not necessarily depend on the date of sowing but on the prevailing weather conditions after sowing. Seed disinfection is likely to be of benefit, therefore, when weather conditions do not favour quick germination. When the seed is infected by seed-borne fungi, the mycelium spreads into the cotyledons and extracts the food reserves that have been stored for the maintenance of the young seedling. Fungi present in the soil may then attack the weakened seed and accentuate the decay. When the seed germinates more quickly, however, as it usually does in later sowings, the root system is soon established, green leaves are formed, and the plant is able to obtain its own food supplies.

FIELD BEANS. There are two important diseases of field beans, Chocolate Spot (*Botrytis spp.*) and Sclerotinia Disease or Bean Rot (*Sclerotinia Trifoliorum*). The cause of Chocolate Spot has hitherto been attributed to *Botrytis cinerea*, but more recent researches at the Long Ashton Research Station indicate that a new species of *Botrytis* may be responsible, viz. *B. Fabae*. It may be, however, that both species are associated with the disease. Bean pods are sometimes severely affected with

Chocolate Spot and the fungus may cause brown markings on the seed coat. It is possible, therefore, that the disease may be carried over with the seed. It is not a common occurrence, however, and the various discolorations often found on bean seeds cannot always be attributed to this cause. The fungus causing Bean Rot is not carried on or in the seed but it is probable that bean samples sometimes contain sclerotia of *Sclerotinia Trifoliorum*, and that these are sown with the seed.

Neither Chocolate Spot nor Bean Rot can be prevented by seed disinfection, but the question arises as to whether such treatment is of value in protecting the seed during its initial stages of germination. Experiments at Cambridge showed that seed treatment with an organo-mercury seed dressing had little effect on growth and yield, and there was no obvious indication that the plants grown from treated seed were less affected by disease than those arising from untreated seed.

SUGAR BEET AND MANGOLDS. The underground parts of sugar-beet and mangold seedlings sometimes turn black and become thread-like. This condition is called Blackleg, and much research has been, and is being, devoted to determining its cause, especially in those Continental countries where the sugar-beet crop has been grown for a long time.

One form of Blackleg is associated with the fungus *Phoma Betae* and infection occurs from the dormant mycelium in the seed clusters, or more rarely from spore cases (pycnidia) embedded in them. It is possible that it may also arise from the residues of a previous beet crop in which the fungus has overwintered. The seedling symptoms of this type of Blackleg are disease lesions on the young stems at, or just below, soil level ; these increase in size and later the roots become black and thread-like, and the seedlings wilt and die. Affected seedlings do not occur in patches but are evenly distributed throughout the field, and sometimes, especially when conditions for germination are cold and wet, a heavy mortality results.

The term Blackleg, however, is often used in a wider sense to embrace somewhat similar injury caused by other fungi. These are not seed-borne, but soil-inhabiting, and include *Pythium*, *Aphanomyces* and *Rhizoctonia*. If the diseased seedlings

occur in definite or localised patches in the field it is likely that one of these fungi may be the causal agent ; if this is so, it is probable that some abnormal condition of the soil exists and has predisposed the plants to attack. The various types of Blackleg must not be confused, however, with injury caused by the Pigmy Mangold Beetle (*Atomaria linearis*), and they must not be mistaken for the condition known as Stringy Root.

The early symptoms of beetle injury are easily distinguished from Blackleg by the small excavations that the beetle bites out from the stem of the seedling just below ground level. Such seedlings may eventually succumb to fungus attack and give rise to Blackleg.

Stringy Root is not primarily due to any fungus or insect pest, but to faulty nutrition. It is common on acid soils. The main root and stem axis fail to swell normally and they are thin and " stringy," but the tissues do not usually become black and rotten as they do with Blackleg.

Control Measures. A good crop of sugar beet depends very largely upon a full and even plant distribution, and it is highly desirable that the seedling mortality should be reduced. This is especially so in years when circumstances favour disease, and the weather is cold and wet and germination slow. It is for this reason, therefore, that all sugar-beet seed is treated before it is dispatched to the farmer. An organo-mercury seed dressing is used, and the treatment is carried out by the sugar-beet factories that supply the seed. This is a wise precautionary measure and an insurance against losses that, although of little consequence one season, might be of vital importance in another. Further, the cost and trouble that the treatment entails are negligible when compared with the advantages that may be derived from it. Seed disinfection, however, will not prevent seedling ailments that arise from faulty nutrition or acid soils.

SWEDES AND TURNIPS. Dry Rot is a disease caused by the fungus *Phoma lingam*, and it attacks both swedes and turnips, especially swedes.

The acute symptoms of Dry Rot are usually not observed until late summer or early autumn, when brown, sunken areas appear on the upper or middle portions of the " root."

As the disease gains a hold, the sunken areas increase in size and eventually gaping cracks appear on the surface. These wounds serve as a breeding-ground for flies that feed on decaying vegetable matter, and also for saprophytic fungi and bacteria. The tissues are then further broken down and a wet rot often develops. If the affected parts remain relatively firm, however, small black dots (about the size of a pin point) can be seen on the surface. These are the spore cases (*pycnidia*), and in them the fungus spores are produced.

The same fungus (*Phoma lingam*), besides causing Dry Rot, is also responsible for Canker of seed crops of swedes and other *Brassicae*. The crop is attacked at soil level, and dry, ashen-grey lesions, studded with pycnidia, appear on the diseased areas. This infection, which is often associated with injury caused by the Cabbage Stem Flea Beetle (*Psylliodes chrysocephala*), restricts the flow of sap to the flowering stalks, and weakens the stems so that they collapse and fall over. It is now known that the Dry Rot and Canker fungus not only attacks the " roots " but also the leaves, seed pods and seeds. At one time it was suggested that infected seed was the chief source of Dry Rot and Canker, but detailed experiments at the University of Reading have shown that this is not so. Indeed, it has been proved that the number of infected seeds in ordinary commercial stocks is extremely low, and rarely exceeds 0.2 per cent. It is true that infected seed may give rise to the disease but it is not the chief cause. The important sources of infection are débris of a previously diseased crop, manure contaminated with pieces of rotten roots, and certain weeds—such as charlock, white mustard, and wild radish—that can also harbour the disease. Control is difficult, for the causal agent may be seed-borne, soil-borne, or carried over from season to season by weeds.

Control Measures. It is sometimes recommended that swede and turnip seed should be disinfected with an approved organo-mercury seed dressing. It is most improbable, however, that this measure alone would be successful in preventing the disease. The best control lies in clean farming, and a sound sequence of cropping where *Brassica* crops do not follow too frequently in the rotation. Where there is unburied rubbish (the débris of a previous swede, turnip, kale

or cabbage crop), the disease is most likely to appear, especially in crops grown for seed.

CELERY. The most important disease of celery is Leaf Spot, or Blight as it is sometimes called, and the cause of it is the fungus *Septoria*.

The symptoms of Leaf Spot are diseased spots on the leaves and leaf stalks, and in a severe attack these often merge together until a substantial portion of the leaf surface is affected. In the early stages the spots are pale green, but as the fungus penetrates more deeply into the tissues the green cells are killed and the affected areas turn a greyish-brown. If the spots are examined with a hand lens it will be seen that the diseased areas are closely studded with a large number of black spore cases (pycnidia). These symptoms, however, should not be confused with injury caused by the Celery Fly maggot, which burrows its way between the upper and lower surfaces of the leaf.

Until recently it was thought that only one species of *Septoria* occurred on celery in this country, but it is now known that there are two, *S. Apii* and *S. Apii-graveolentis*. The chief differences are that with *S. Apii* large brown spots bearing a few pycnidia are formed, whereas with *S. Apii-graveolentis* more numerous but smaller, greenish or greyish-brown spots bearing many pycnidia occur. In Britain, it is the latter that is the more common and injurious.

Leaf Spot arises from the sowing of infected seed, for the pycnidia are embedded in the seed coat. The majority of commercial seed samples are infected, as the following figures show. During the twenty-one-year period 1926-47, 960 samples of celery seed were examined at the Official Seed Testing Station, Cambridge, and of these only 123 (just under 13 per cent.) were free from infection. Of the remainder, 546 showed up to 20 per cent. infection, 234 from 20 to 60 per cent., 47 from 60 to 80 per cent., and 10 over 80 per cent.

When infected seed is sown innumerable thread-like spores ooze out from the pycnidia and infect the young seedlings. Infection is favoured by moist conditions, and especially by overhead watering and insufficient ventilation. Later, when the seedlings are pricked out into the beds, new infections

occur, but these are usually overlooked and it is not until the plants are transferred to the field that the disease is noticed. If conditions favour spore dispersal and infection, the crop becomes so badly blighted that it is marketed at a loss. In wet weather the spore cases release spores and these are scattered by the impact of falling raindrops, and splashed on to leaves in the immediate vicinity. In this way nearby healthy plants become contaminated. Wet weather does not necessarily imply, however, that a severe attack will develop, for in such circumstances the crop grows vigorously and is better able to withstand the disease. Severe damage is more likely to occur when the crop grows slowly, as it does during a dry spell when there are drying winds and insufficient moisture, and the nights are cool, dewy or misty.

Why is this destructive disease so prevalent ? The majority of commercial seed samples are infected, and farmers who grow their own stocks seldom produce disease-free seed. Celery growers should demand a guarantee from their seed merchants that the seed sold is free from disease, and those who grow their own stocks should be satisfied with no lower standard. Reports on the health of samples of seed (that should consist of not less than 200 seeds) may be obtained for a fee of 2s. from the Official Seed Testing Station for England and Wales, Huntingdon Road, Cambridge.

Control Measures. If disease-free seed cannot be obtained, the seed used should be disinfected by steeping it for 3 hours in a solution made up of 1 part of formalin (40 per cent. strength) in 300 parts of water. It should be dried thoroughly after treatment (if it is to be kept for any length of time), otherwise poor germination may result. This treatment also reduces the risk of Root Rot caused by *Phoma apiicola*, another seed-borne disease. Unfortunately seed disinfection with formalin does not entirely eliminate Leaf Spot, although it very markedly reduces the number of diseased seedlings. A few diseased plants in a box or frame may seem unimportant, but they are a potent source of infection. The spores they produce are scattered among the crowded seedlings, and, if the leaves are wet, the spores germinate and cause infection. It is inevitable, therefore, that when the plants are transferred to the field there are scattered focal centres from which the disease may

spread. To guard against infections from these sources it is necessary to spray the crop at intervals with a protective fungicide, such as Bordeaux mixture.

The best remedy for celery Leaf Spot is *disease-free seed.* This is not difficult to produce and can be obtained by regularly spraying the plants to be grown on for seed with Bordeaux mixture, or some other suitable copper preparation. The most important applications of the spray are those given whilst the plants are flowering and setting seed.

A brief review has now been given of the more important diseases of farm crops that arise from the sowing of contaminated or infected seed stocks, and it has been shown that many of them can be prevented by treating the seed with a suitable seed disinfectant or seed protectant. It remains now to consider diseases that originate from soil-inhabiting fungi, for these are not amenable to such simple preventive measures.

c

d

Celery Leaf Spot (*Septoria Apii-graveolentis*): (*c*) A leaf petiole (enlarged) covered with pycnidia. (*d*) Photomicrograph of a section through a pycnidium on the leaf.

PLATE XXXIV

Take-All and Whiteheads of wheat (*Ophiobolus graminis*):

(*a*) Wheat seedling—the roots attacked by runner hyphae.
(*b*) Photomicrograph of runner hyphae.
(*c*) Affected plant with diseased roots, and base blackened with plate mycelium.
(*d*) Blind ear (whitehead) discoloured by saprophytic moulds.
(*e*) Photomicrograph of plate mycelium on stem base.
(*f*) Photomicrograph of immature perithecia.

PLATE XXXV

a

b

Violet Root Rot (*Helicobasidium purpureum*):

(*a*) On sugar beet.
(*b*) On carrot.

PLATE XXXVI

Clover Rot
(*Sclerotinia Trifoliorum*) :

(*a*) Dead clover plant with sclerotia.

(*b*) Apothecia growing from sclerotia in clover débris on the surface of the soil.

(*c*) Apothecia growing from sclerotia in the soil.

a

b

c

Chapter Eleven

Soil "Sickness"

A well-planned sequence of cropping enables fertility to be maintained, permits an economical distribution of labour throughout the year, and assists materially in suppressing weeds and preventing an accumulation of harmful organisms in the soil.

Although the advantages of a sound rotation are generally appreciated, it is sometimes said that the same crop can be grown year after year on the same field without any ill effect. This is a dangerous conception, for it is the common experience of plant pathologists that harmful pests and fungi accumulate in the soil and disease subsequently appears. Fields carrying the same crop too frequently serve as a focal point for the spread of harmful pests and diseases to neighbouring crops, or even to those much further away. The danger incurred arises mainly from soil-inhabiting organisms, and to a lesser extent from the distribution of airborne spores. Diseases arising from the latter can sometimes be prevented by the use of resistant varieties, or the application of fungicidal sprays, but, if resistant varieties are not available, soil pests and fungi must be starved from the land by withholding food plants on which they normally feed. This entails a careful sequence of cropping.

During the period between the two Great Wars, when agriculture was at a low ebb, Take-all of wheat and barley was very prevalent on many farms. Cash crops were necessary and corn followed corn. Bleached and shrivelled ears appeared, but these warning signals went unrecognised, or unheeded. More white straw crops followed in succession—the decrease in yield and the increase in tail corn then became all too evident.

TAKE-ALL AND WHITEHEADS (*Ophiobolus graminis*). The Take-all and Whiteheads disease of corn crops and grasses is caused by the fungus *Ophiobolus graminis*. It survives in the

soil either in the root and stubble residues from a previous infected crop, or on the roots and haulm of infected grasses. The first signs of Take-all are patches of unhealthy-looking plants with yellowing outer leaves, but the symptoms often pass unrecognised, and it is not until bleached and whitened ears are seen that the presence of the disease is suspected. It is the appearance of these bleached ears that has led to the use of the term Whiteheads, but a somewhat similar condition may arise from other causes. Usually, however, it is an indication that *Ophiobolus* has become established in the soil.

Fortunately the remedy is simple, for the disease can be prevented by a sequence of cropping in which wheat and barley are not taken at too frequent intervals. When Take-all has appeared, the inclusion of a non-cereal crop, such as the root-break in the Norfolk 4-course rotation, is usually a sufficient precaution, except for very light-textured soils or those overlying chalk, when the land should be kept free from susceptible crops for two years. If the land is foul with weed grasses such as couch, slender foxtail, and Yorkshire fog, however, the fungus will survive for longer periods and the disease will be more difficult to control.

VIOLET ROOT ROT (*Helicobasidium purpureum*). When sugar beet, mangolds, carrots and potatoes are grown too frequently on the same field, Violet Root Rot usually appears, especially if the land is not too well drained. The disease is caused by *Helicobasidium purpureum*, another soil-inhabiting fungus. The first warning signs are frequently neglected, and the appearance of a few beet, mangolds or carrots with their roots covered with a purple felt of fungus spawn is dismissed as of little or no consequence, and it is not until the fungus has become well-established that concern is expressed.

By the use of steam, or certain chemical disinfectants, the cultivator of glasshouse crops can partially sterilize the soil to kill harmful organisms that may be present, but the farmer cannot do this as the cost of the treatment on a large scale is prohibitive. A simple, cheap and effective remedy for " disinfecting " large acreages has yet to be discovered. In the meantime, a sound sequence of cropping must be adopted.

Take-all and Violet Root Rot do not jeopardise a neigh-

bour's crop, as do certain other soil-borne fungi, and some of these will now be considered. When red clover is grown too frequently on the same land the crop may fail, and the field become "clover-sick." This "sickness" is sometimes due to the presence in the soil of the clover strain of the Stem Eelworm (*Anguillulina dipsaci*), but it also originates from the Clover Rot fungus (*Sclerotinia Trifoliorum*), and it is "sickness" arising from this cause that is now described.

CLOVER ROT (*Sclerotinia Trifoliorum*). The first sign of Clover Rot is a "peppering" of the foliage with small, brown spots. These symptoms appear in the late autumn, but it is not until the leaves turn brown and widening patches of dead plants are noticed that the disease is usually recognised. In the early stages, the dying leaves are covered with a thin, fine weft of mycelium, but later sclerotia are formed—resting bodies consisting of compact masses of mycelium, white in colour at first but finally becoming black. They develop mainly at the base of the stem and in the crown and upper part of the root, and they vary considerably in size; some are as large as a pea, and others as small as a pin's head. It is these bodies that contaminate the soil and are responsible for subsequent attacks of Clover Rot. During the summer they remain dormant, but in the early autumn those near the surface of the soil germinate and give rise to flesh-coloured, saucer-shaped, stalked bodies called apothecia; these bear asci containing the ascospores that spread the disease. Other sclerotia more deeply situated in the soil may remain dormant for many years, but when cultivations bring them within an inch or so of the surface, they too may germinate and produce spores that are carried by the wind to nearby plants or neighbouring fields.

Clover Rot is much influenced by the weather, and in a mild winter following a wet autumn it spreads rapidly. When dry, frosty conditions prevail the disease is checked and partial recovery often follows.

The various kinds of clover and allied plants are not all equally susceptible to Clover Rot. Common or broad red clover is most frequently attacked and suffers severely, but late-flowering red clover (single-cut cow-grass) is also very susceptible. Alsike and white clover are not so readily affected.

Trefoil is often attacked, but, although partial failures are not infrequent, it withstands the disease better than red clover. Clover Rot sometimes appears in sainfoin and lucerne during their first year, but increasing resistance is shown after one season's growth. Vetches are very rarely affected, and peas appear to escape the disease. Field beans, however, especially when winter-sown, are susceptible to a varietal form of the Clover Rot fungus. Bean Rot, the disease that it causes, does not usually become very evident until about mid-March or early April, but plants continue to die until harvest. The fungus affects the plant at or about soil level, the mycelium progressing upwards into the stem and downwards into the root, with the result that the plants ultimately wither and die. If the disease is in an advanced state, and affected plants are pulled up (they come away very easily, and this is a useful diagnostic feature), sclerotia will be found attached to the root or enclosed inside the stem.

The remedy for Clover and Bean Rot is a sound sequence of cropping in which susceptible crops are not grown too frequently. On land where Clover Rot has become established, an interval of at least eight years should be allowed before common red clover and late-flowering red clover are grown again. In the intervening period, sainfoin or lucerne can be sown (provided there is sufficient chalk in the soil), or alsike or white clover can be taken, either alone or with Italian rye-grass. Peas or vetches may also be substituted, but not beans.

Fungi are not the only harmful organisms that may accumulate when specific crops are grown too frequently on the same field, for the land may become populated with parasitic eelworms, and when this occurs serious consequences may ensue. Notable examples of troubles that arise in this way are sugar-beet "sickness," and a very similar malady that affects the potato.

BEET EELWORM (*Heterodera schachtii*). Although the Beet Eelworm, the cause of "beet sickness," has been prevalent on the Continent for nearly a century, it was not discovered in England until 1928, when it was found on mangolds, and a few years later, in 1934, on sugar beet. It is now known that the chief centres of infestation are the Isle of Ely and

Norfolk, but smaller areas also exist in several other counties.

The Beet Eelworm, besides attacking sugar beet, red beet, mangolds and spinach, also affects plants of the cabbage family (*Cruciferae*), namely, turnips, swedes, cabbages, cauliflowers, broccoli, brussels sprouts, kale, rape, kohl-rabi, cress, mustard and radish. Weeds such as fat hen and charlock also harbour the pest. It is not a source of danger, however, to potatoes or other farm crops.

The first sign of "beet sickness" is the appearance of a small patch or patches of stunted plants, the outer leaves of which are wilted and yellow. The tap root is small and short, and affected plants are easily pulled from the soil. A characteristic feature of the root system is the excessive development of lateral rootlets, many of which are dead. On these are small lemon-shaped cysts about the size of a small pin's head, creamy-white at first, but later becoming brown. These structures, which become detached from the roots and fall into the soil, are the dead bodies of female eelworms, and contained within them, and thus protected, are many eggs—a large cyst may contain several hundred. During the winter the eggs remain dormant in the soil, but in the spring some of them hatch, and if the right hosts are present the young eelworms penetrate their roots. Only some of the eggs hatch each year, however, and others remain alive for several years. It is clear, therefore, that if susceptible crops are grown too frequently "beet sickness" will appear.

Great care should be taken to see that land that is free from this pest does not accidentally become contaminated. Once established the eelworm is a grave source of danger, for the cysts can be carried from place to place in soil adhering to boots, implements, carts and the hooves of livestock, or in the earth attached to the roots of seedlings used for transplanting. No effective and economical method of killing the eelworms in the soil has yet been discovered, and the only remedy is to starve the pest by withholding the crop plants on which it feeds. On land that is slightly infested, beet and other susceptible crops should not be grown more frequently than once in every four years, and on fields that are heavily infested a period of at least five years should elapse.

POTATO EELWORM. There are two distinct kinds of eel-

worm that attack the potato, the Root Eelworm (*Heterodera rostochiensis*), and the Stem Eelworm (*Anguillulina dipsaci*). The former, as its name implies, attacks the roots and causes affected plants to become dwarfed and sickly; the Stem Eelworm infests the tubers and sets up a form of dry rot that may easily be mistaken for injury caused by the Potato Blight fungus. In blighted tubers the skin over the discoloured area is usually firm and intact, but those affected with Stem Eelworm are slightly softer and show a characteristic cracking over the surface. The only certain distinguishing feature, however, is the presence of the parasite, and this must be determined by microscopic examination. Although the Stem Eelworm is probably more prevalent than is suspected, it is not nearly so serious as the Root Eelworm. This pest (*Heterodera rostochiensis*) was first recorded in Scotland in 1913, and then in 1917 in Yorkshire. It has now established a firm hold and is widely distributed throughout Britain, especially where early potato varieties are grown.

The most obvious sign of "potato sickness" is the appearance of a patch or patches of dwarfed and sickly plants. The lower leaves are withered, the foliage paler in colour than is normal, the stems spindly and the root system poor. Affected plants die prematurely, and when they are pulled up eelworm cysts are found on the roots. At an early stage they are dull-white in colour, but later turn brown. As with the Beet Eelworm the cysts fall into the ground, and later the eggs hatch to produce young eelworms. Unlike the Beet Eelworm, however, the Potato Root Eelworm is more restricted in its host range, for the only other farm crop that it infests is the tomato.

Satisfactory chemical treatments for killing eelworms in the soil have not yet been devised, and the only remedy is to starve the pest from the land by not growing potatoes too frequently. After slight or moderate attacks, potatoes should not be grown more often than once in four years, and, after a severe attack, they should not be taken for at least five years. Care must also be taken to prevent infested soil from reaching clean land, for it may contain cysts and so lead to a new centre of infestation. For example, this may occur if seed tubers or transplants are obtained from eelworm-infested soil.

It is usually from some focal point that disease spreads, and common sources of danger are weeds and "groundkeepers"—volunteer plants that have grown from previous crops. Examples are potato plants arising from tubers missed at lifting time, and the self-set tops of sugar beet. "Groundkeepers" are more important than is generally realised, for not only are they dangerous sources of disease, but they are also bridges that span the intervening years between the growing of susceptible crops. In this way, self-sown potatoes serve as distributing centres for the Root Eelworm, Potato Blight and virus diseases; self-sown sugar beet and mangolds harbour Beet Eelworm, Downy Mildew and Virus Yellows; and land foul with grass weeds provides host plants for the Take-all fungus.

It is clear that the losses caused by soil-borne diseases can very largely be avoided by clean farming, and a sound sequence of cropping.

Chapter Twelve

Soil-inhabiting Fungi that cause Disease

Although the soil appears to be an inert mass of mineral particles and organic matter, it is the natural habitat of countless bacteria, fungi and protozoa, an immense soil population in relation to which the surface plant population is numerically small.

Among this population there exists a complex biological relationship, which varies to a great extent with soil type and environment. It is upon a fine balance of these soil-inhabiting organisms that fertility largely depends. Most of them are saprophytes, but some are parasitic and cause plant disease. The influence of cropping sequence on the incidence of plant disease has already been considered in the previous chapter in relation to Take-all of cereals, Clover Rot and Violet Root Rot. There are soil-borne diseases, however, for which additional precautions besides adopting a safe rotation may be necessary, and in which soil conditions may be a vital factor. The four diseases that will now be considered are examples in which widely different methods of control have been found necessary.

CLUB ROOT (*Plasmodiophora Brassicae*). Club Root, or Finger-and-Toe as it is sometimes called, is a well-known disease that affects both cultivated and weed plants of the Order *Cruciferae*, such as cabbage, turnip, radish and wall-flower. It is caused by *Plasmodiophora Brassicae*, until recently regarded as one of the slime fungi or *Myxomycetes*, but now included among the *Phycomycetes* in the Order *Chytridiales*. It persists in the soil for very many years, but if the land becomes badly contaminated it cannot always be eliminated simply by adopting a sound rotation.

The disease was first recorded in Britain in the early part of the eighteenth century and it is now widespread and of considerable economic importance. Infected roots become deformed, swollen and shapeless, and the plant is unable to

PLATE XXXVII

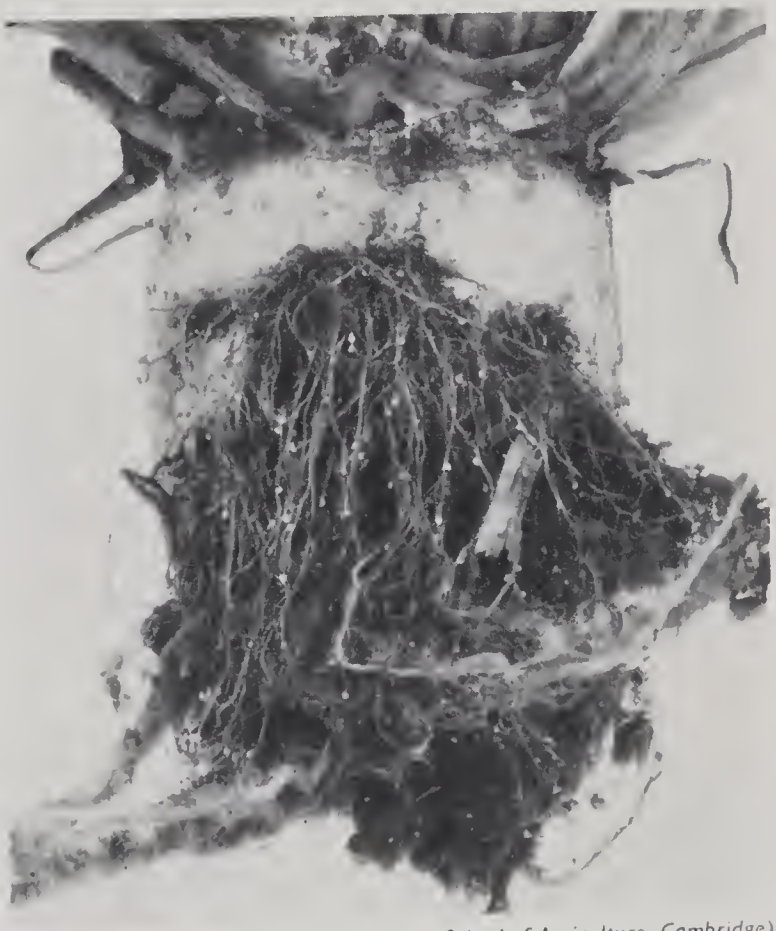
a

b

Sclerotinia Disease of Bean—Bean Rot (*Sclerotinia Trifoliorum*):
(*a*) Diseased bean plant in a field crop.
(*b*) Bean stalk cut lengthwise to show sclerotia.

PLATE XXXVIII

1 (By permission of Mr. F. R. Petherbridge, School of Agriculture, Cambridge)



2 (By permission of Mr. F. R. Petherbridge, School of Agriculture Cambridge)

1. Beet "sickness"—a patch of stunted plants infested with eelworm (*Heterodera schachtii*).
2. Sugar beet with roots infested with eelworm cysts.

PLATE XXXIX

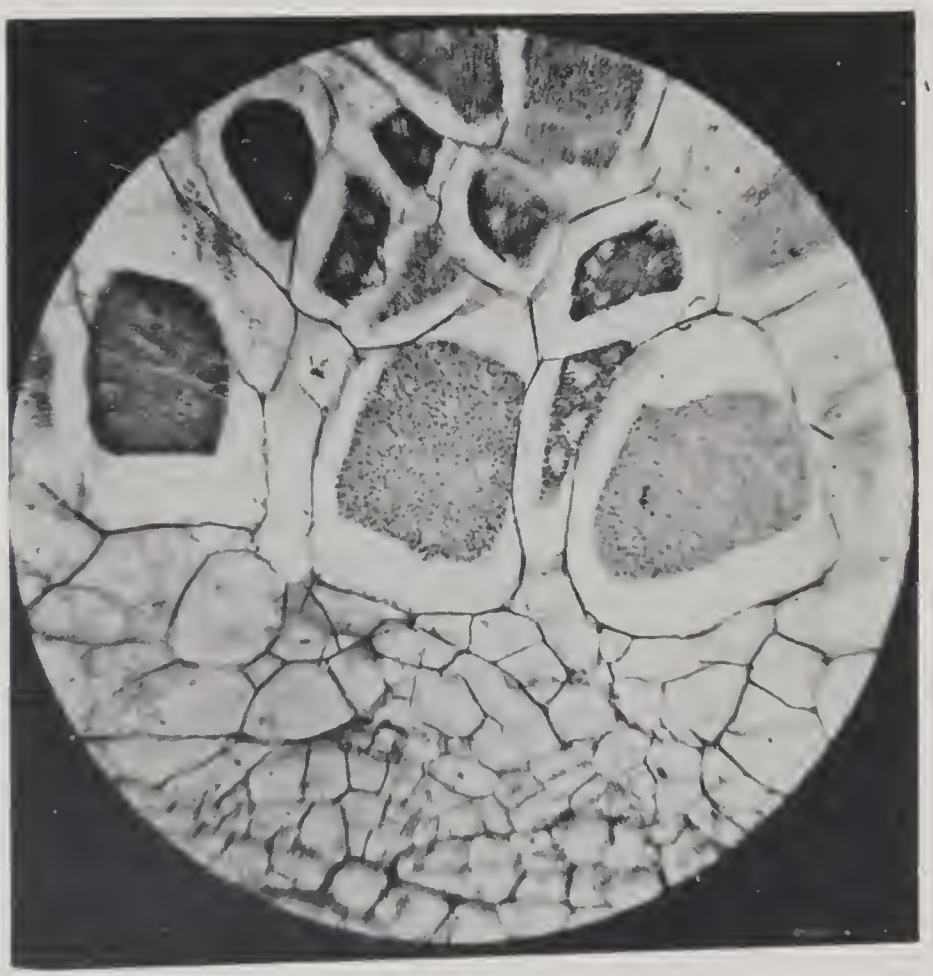
a (By permission of Mr. F. R. Petherbridge, School of Agriculture, Cambridge)

b (By permission of Mr. F. R. Petherbridge, School of Agriculture, Cambridge)

Potato root Eelworm (*Heterodera rostochiensis*) :
(*a*) Field symptoms of potato "sickness." (*b*) Eelworm cysts on a root (enlarged).

PLATE XL

a



b

Club Root of cabbage (*Plasmodiophora Brassicae*): (*a*) Diseased root. (*b*) Photomicrograph of a section through the diseased and swollen tissue. The enlarged cells contain the plasmodia of the parasite.

derive sufficient nourishment from the soil. Severely infected plants are stunted and apt to collapse in hot, dry weather. Severe attacks are normally associated with sour, badly-drained soils that have carried cruciferous crops too frequently —conditions favourable to the increase and survival of the parasite.

As its persistence is intimately linked with adverse soil conditions, it is in this direction that control measures should be sought. Drainage should be improved and dressings of lime applied to reduce acidity. As lime is gradually leached from the soil, losses must be replaced periodically by further applications. Freshly-slaked burnt lime, hydrated lime or ground quicklime are best, other forms such as chalk and ground limestone are not so satisfactory. The effect of the lime may not be immediate, however, as some time usually elapses before it becomes thoroughly incorporated into the soil. To be most effective it should be applied in a finely-divided state the season preceding the planting of the susceptible crop.

Another possible means of control is the use of resistant varieties. The Danish varieties of swede—*Wilhelmsburger*, *Bangholm Studsgaard* and *Bangholm Hernig*—possess a high degree of resistance, which has been substantiated by trials in England and Wales. A yellow-flecked, purple-topped variety of turnip, *The Bruce*, is highly resistant, and also the green-topped variety, *The Wallace*.

Apart from the control measures already given, the period between susceptible crops should be increased and care taken to keep down all cruciferous weeds which may harbour the parasite. Diseased material should be burnt and infected crops folded *in situ* rather than carted off the field, for the spores are carried in the dung and may contaminate fresh land.

On germination the spore forms an amoeboid body possessing a single cilium, with which it can swim for a short time in the soil water. Later it loses its cilium and forms a myxamoeba. The majority of myxamoebae ultimately perish but those that reach a cruciferous plant penetrate the root, probably through the root hairs, and there grow rapidly into plasmodia consisting of granular masses of protoplasm that penetrate the neighbouring cells of the roots. Infected cells

and those adjacent to them become enlarged and the nearby tissue rapidly proliferates to form the large swellings so characteristic of the disease and from which it gets its name. The plasmodia later divide up to form spores that completely fill the infected cells. When the swellings break down, the spores become incorporated in the soil, where, if conditions are favourable to the parasite, they may remain viable for many years.

The rounded swellings produced on the roots and stem bases of crucifers by a very common pest, the Gall Weevil, are often confused with those of Club Root. The former, however, are usually hollow and contain the small white maggot of the weevil. With Club Root, if the swellings are cut across, the exposed surfaces have a grey appearance with lighter opaque patches corresponding to the enlarged cells, giving a marbled effect.

WART DISEASE (*Synchytrium endobioticum*). Another soil-borne disease of considerable importance in some parts of Britain is Wart Disease of potato, caused by *Synchytrium endobioticum*. This fungus is closely related to the Club Root organism but very different methods of control have been adopted. The disease was first described in Hungary at the end of the nineteenth century, since when it has become widespread in Europe, and is now found in the U.S.A. and South Africa.

Symptoms of the disease are warty excrescences appearing on the " eyes " of tubers, or more rarely on buds or leaves at the base of the stems ; roots are not affected. The warty masses are the result of rapid proliferation of the host tissue induced by the presence of the parasite. Severely affected tubers may be almost entirely encrusted with tumour-like growths. If thin sections of young wart tissue are microscopically examined, many of the cells will be seen to contain large, round, brown structures, some with relatively thin walls and others with irregularly thickened walls much darker in colour. These are sporangia. When the warty tissue rots, the thick-walled sporangia pass into the soil where they are capable of surviving for very many years. Eventually they liberate numerous zoospores, each equipped with a cilium with which it can swim in the soil water : it is for this reason that

most severe losses occur in wet soils. On reaching host tissue unprotected by periderm, such as the " eye " of a tuber, the zoospores penetrate the epidermal cells, live upon the cell contents and increase in size, giving rise to thin-walled " summer " sporangia. These produce more zoospores, which either cause fresh infections and give rise to more summer sporangia or fuse together in pairs. Fused pairs of zoospores also cause infection but give rise to thick-walled resting sporangia. Owing to the greater length of time required for their development, they are usually observed in the deeper layers of the affected tissue, while summer sporangia are more abundant nearer the surface.

The presence of resting sporangia in the soil and their great longevity make measures of control such as resting the land and soil treatment neither practicable nor economic. Indeed, Wart Disease has been known to occur in crops after a twelve-year interval during which potatoes were not grown. Certain varieties of potato, however, are more readily affected by the disease, and some are highly resistant or immune. On this knowledge rests the only practicable way of ensuring the limitation of the disease.

Contaminated land should be planted with field-immune varieties, and in addition care should be taken to minimise the spread of infected material. The use of dung from stock fed on diseased tubers, unless these are thoroughly cooked, is a potent means of distributing the fungus.

The losses due to Wart Disease in Britain are now very slight, but the disease is still of great potential significance and must be kept in check, for once land has become contaminated it may remain so indefinitely. For this reason Wart Disease is scheduled in an Order made under the Destructive Insects and Pests Acts, which requires that the Ministry of Agriculture shall be notified of all new occurrences of the disease. Under the provisions of the Order, the sale of visibly infected tubers for any purpose is prohibited ; no potatoes from a crop in which the disease has been found may be sold or offered for seed purposes ; and only potatoes of approved immune varieties may be planted on land on which Wart Disease has occurred at any time.

Some Commercial Varieties Immune from Wart Disease

Early : Arran Pilot, Ballydoon, Di Vernon, Doon Early, Snowdrop (Witch Hill), Ulster Chieftain.

Second Early : Arran Comrade, Arran Luxury, Arran Signet, Ben Lomond, Catriona, Dunbar Rover, Edzell Blue, Great Scot.

Early Maincrop : Arran Banner, Arran Peak, Doon Star, Gladstone, Majestic, Redskin.

Late Maincrop : Arran Consul, Arran Victory, Dunbar Standard, Golden Wonder, Kerr's Pink.

Some Commercial Varieties Susceptible to Wart Disease

Early : Eclipse, Epicure, Duke of York, May Queen, Ninetyfold, Puritan, Sharpe's Express.

Second Early : British Queen, Royal Kidney.

Early Maincrop : King Edward VII.

Maincrop : Arran Chief, Up-to-Date.

DRY ROT (*Fusarium caeruleum*). The soil-borne diseases considered so far have required for their control a safe sequence of cropping, the correction of unfavourable soil conditions or the use of resistant varieties. There are, however, some that cannot satisfactorily be controlled by any of these methods. A good example is Dry Rot of potatoes, a disease caused by *Fusarium caeruleum.* This parasite is a member of the *Fungi Imperfecti.* Dry Rot has long been known to cause severe losses in storage and also considerable reductions in yield due to gappy crops resulting from planting infected seed.

Although severe losses often occur during the storage of ware potatoes, the disease is primarily one of serious consequence in the production of seed, more especially among the early varieties such as May Queen, Ninetyfold, Arran Pilot and Duke of York, which are most susceptible. Among the early maincrop and maincrop varieties, Doon Star and Majestic are also particularly susceptible. As the storage season advances and the tubers become more mature their susceptibility to Dry Rot increases.

The fungus is primarily a wound-parasite, although it is capable also of attacking potatoes having unbroken skins, possibly through the " eyes," lenticels or scab lesions. Careless handling causing cuts, bruises and abrasions renders tubers more subject to attack. Infection most frequently starts from a cut or bruise and the rot at first appears as a brown discoloration of the skin and underlying flesh of the tuber. This

quickly increases in size and becomes sunken. As the area increases the skin wrinkles in typical concentric rings owing to the shrinkage of underlying tissue.

The flesh of infected potatoes is brown and usually contains cavities. At this stage the fungus produces sporing pustules. These are greyish-white, but if the superficial mycelium and spores are rubbed off, the pustule is often typically dark-blue, and it is from this colour that *Fusarium caeruleum* derives its specific name. The spores are sickle-shaped with several septa. In these septate conidia, the individual cells are occasionally swollen with thickened walls ; these are resting spores and they can survive in the soil for long periods, but there is no evidence that growth of the fungus occurs in the soil.

The sickle-shaped, septate spores of *Fusarium caeruleum* are typical of the *Fusaria*, of which there are over sixty species. Another *Fusarium* often associated with a dry-rot condition of potatoes in this country is *F. avenaceum*.

As these fungi are primarily wound-parasites it follows that care should be taken in handling all potatoes, particularly if they are intended for seed purposes. In recent years excellent control of the disease has been obtained by disinfecting the seed, but this must be done *immediately upon lifting*. The methods used have involved dipping the tubers either for at least one minute in a proprietary liquid organo-mercury dip, or for about a quarter of a minute in a one per cent. solution of formalin. After treatment the tubers must be dried thoroughly, carefully handled and protected from subsequent recontamination. At present the disadvantage of this method is that it is a wet treatment involving equipment not readily within reach of the small grower upon whom the production of a large proportion of our seed potatoes depends.

The disinfection of seed potatoes will be simplified greatly when suitable dry treatments are developed. Promising results have already been obtained on an experimental basis, using a thymol-kaolin dust. Losses due to gappy crops arising from Dry Rot can be reduced by chitting the seed before planting. In this way the seed can be examined periodically and diseased tubers removed and destroyed.

Many other plant diseases are caused by species of *Fusarium*,

and these are often closely linked with adverse soil conditions and too frequent cropping with susceptible plants.

ARMILLARIA ROOT ROT (*Armillaria mellea*). Three diseases of farm crops have now been described, in which special measures of control have been found to be effective. The fourth example concerns a disease of fruit and forest trees caused by *Armillaria mellea*. This soil-inhabiting parasite is one of the larger fungi of the *Basidiomycetes*, and one that causes disease in a wide variety of trees. As the crops affected are perennial and occupy the land for many years, its control presents a specialised problem.

The fungus grows as a saprophyte on dead tree stumps, round which, in autumn, dense clusters of fruiting bodies are frequently seen. These are the well-known "toadstools" of the "Honey Agaric," so named on account of the honey colour of the cap or pileus. They are about 2-4 in. across and are borne on stalks 3-8 in. in height. The gills on the undersides of the caps produce large numbers of spores which are disseminated by wind or insects to other dead wood, such as fencing-posts and dead stumps. On these and on infected trees, the fungus is present chiefly as a thin weft of white mycelium spreading fanwise between the wood and the bark, but in the soil and on the roots, the fungus forms black strands or rhizomorphs, which have the appearance of shoe-strings—by which name the fungus is sometimes known. It is by means of these organs that the fungus spreads through the soil and parasitises the roots of neighbouring living trees. The mycelium penetrates the roots and from there spreads to the base of the trunk, which it gradually encircles. Complete girdling is followed by the death of the tree. The rhizomorphs (rather than the spores) are mainly responsible for causing infection of living trees, and their presence is a typical symptom of the disease.

Of the many trees that may be affected, the conifers are most susceptible, but apart from these, other plants, including bush fruit and even strawberry and potato, may be affected.

Damage is likely to occur mostly in commercial plantations established on cleared woodland, near old woodland or where old hedges have been uprooted and cleared. In such localities, a great danger exists from infected stumps and roots remaining

in the ground, for these are a source of infection for neighbouring trees. The control measures involve the removal of all diseased trees and infected stumps, and if woodland is cleared to make way for new plantations, care must be taken to remove stumps and roots as these may in turn become sources of infection. Wooden fencing and gateposts should be well protected with creosote, especially on land where the trouble may be expected. Where a tree is infected it should be removed with as much root as possible and a slit-trench $1\frac{1}{2}$-2 ft. deep dug round it to prevent the progress of the rhizomorphs to adjacent trees.

The parasite is most destructive in badly-drained soils and improvement to the drainage assists indirectly in checking the disease. Recent researches on the control of *Armillaria* in tea plantations established on cleared woodland have shown that stumps with roots having a high content of carbohydrate are more readily attacked. This has led to the practice in autumn of ring-barking forest trees before winter-felling, as a means of checking the flow of sap back to the roots and so impoverishing them of carbohydrate. The stumps are then less subject to infection, and even if there is delay in removing them the chance of the disease being introduced into newly-planted trees is reduced.

The four diseases dealt with above have been used to illustrate ways, in addition to the adoption of sound rotations, in which soil-inhabiting fungi are combated. These methods have involved correction of soil abnormalities, the use of resistant varieties, disinfection of propagating material and the destruction of centres of infection. When considering soil-borne fungi that cause disease, the rôle of propagating material (e.g. tubers, cuttings, " stools," pot plants—and even seed) in the transference of inoculum to new land must always receive particular attention. There remains the possibility of eliminating the pathogen from the soil by partial sterilization, a measure that has not hitherto been practicable for large-scale farming operations against soil-borne diseases, but which is used with outstanding success against many of those affecting horticultural crops. Soil sterilization has now become a standard practice amongst most commercial nurserymen, particularly those engaged on intensive tomato production.

Partial soil sterilization may be by steam, baking, or chemical methods, but where steam can be used this is to be preferred. The process involves the raising of the soil temperature as quickly as possible to 212° F., and maintaining this temperature for a further 10 minutes. Various forms of apparatus are used, but all consist of a boiler capable of generating a large and steady output of steam, and systems of piping so arranged that the steam can be injected into the soil at a depth of 12-18 in. Well-known methods are the Hoddesdon system, and the Grid and Harrow methods. The first is now being used to an increasing extent in the larger tomato-growing areas.

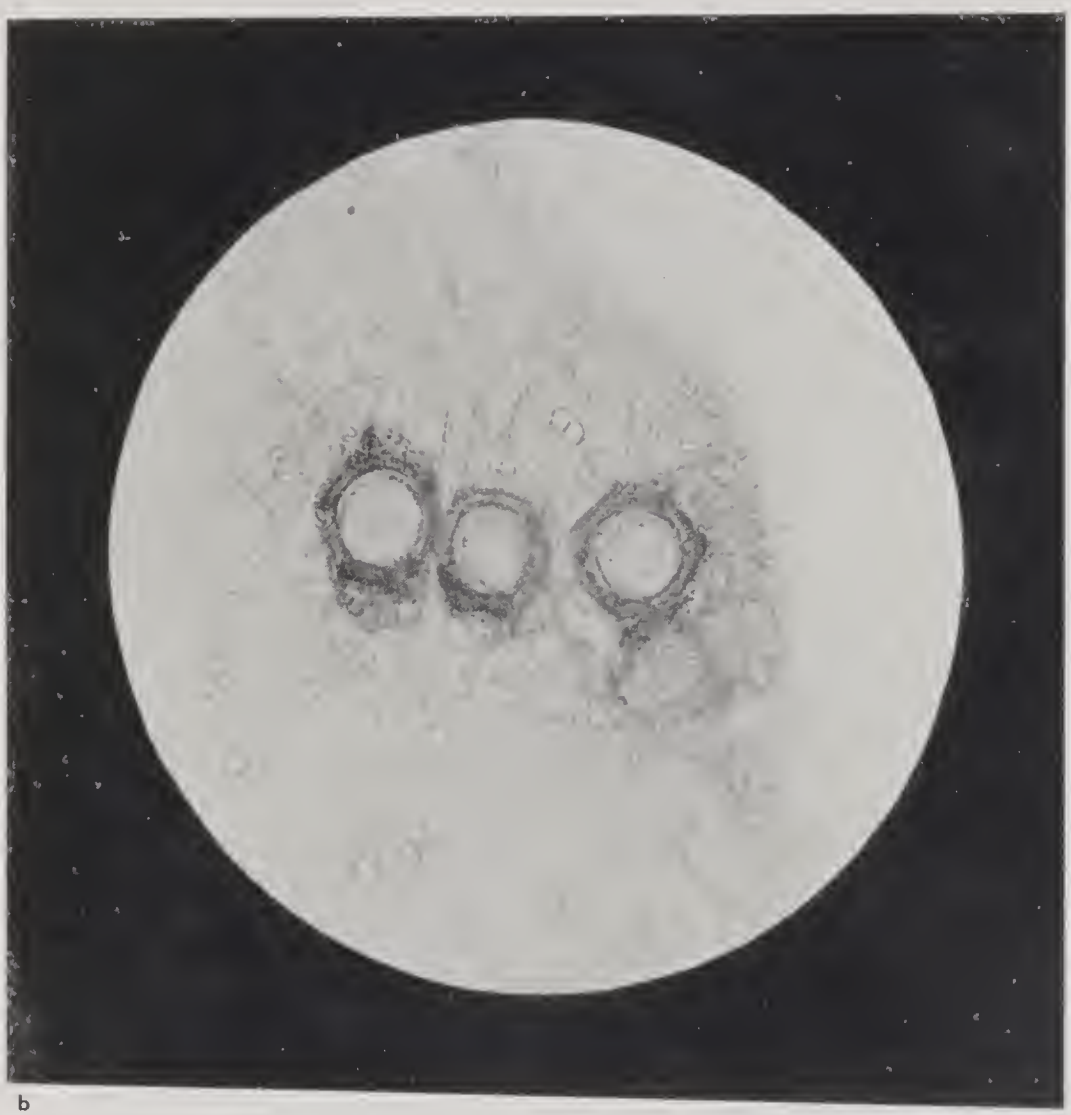
Smaller quantities of soil for potting purposes can be treated similarly, or alternatively may be baked. The soil at the time of steaming should be friable, of fine tilth and sufficiently moist, but not wet. Care must be taken to avoid a lumpy tilth, for the efficiency of the process depends upon all particles of the soil coming into intimate contact with the steam.

Particular attention must also be paid to the thorough steaming of all soil against the walls, under piping and around the stanchions. For chemical sterilization, formalin, cresylic acid or one of the proprietary soil sterilizers may be used. Formalin is most effective, but when soil insects are troublesome, cresylic acid is preferable. Precautions must always be taken to avoid recontamination of the soil and to apply correct after-treatments. Detailed instruction on soil sterilization is given in Bulletin No. 22 and Advisory Leaflet No. 319 of the Ministry of Agriculture.

In the next chapter several important tomato diseases are considered. Some of them are soil-borne, and partial soil sterilization is used as one of the principal control measures.

PLATE XLI

a

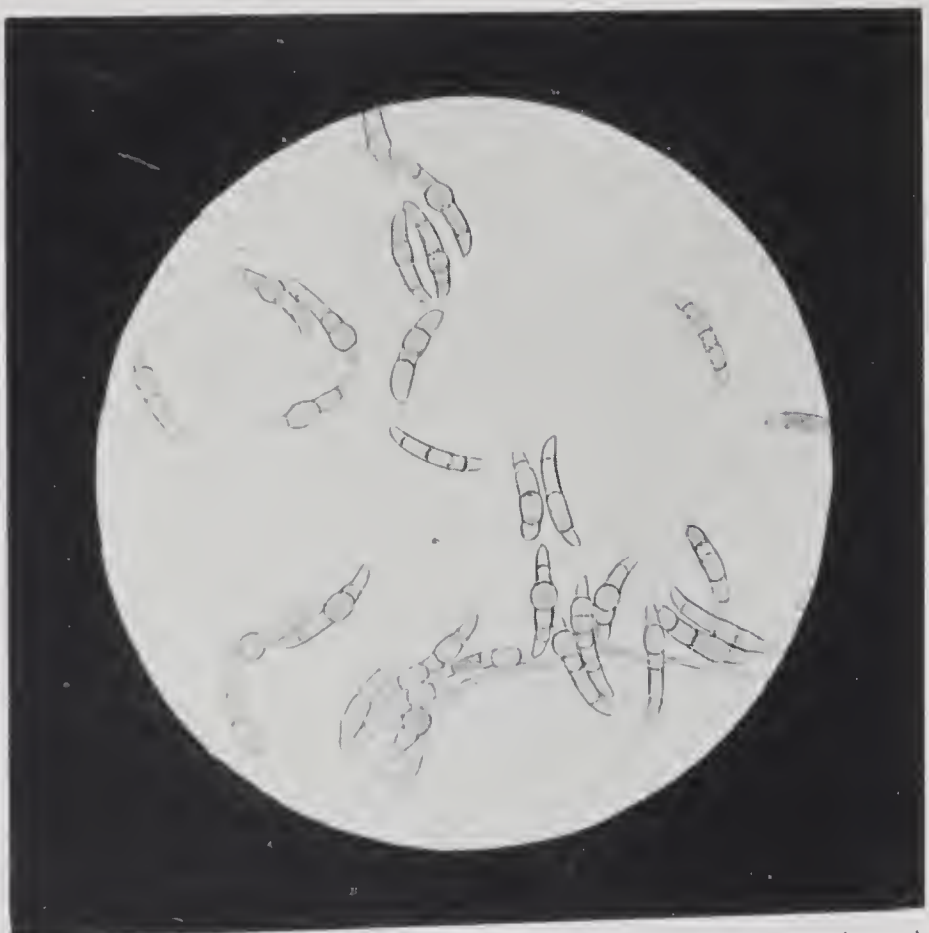


b

Wart Disease of potato (*Synchytrium endobioticum*):
(*a*) Potato stem with tumerous growth at soil level.
(*b*) Photomicrograph of a section through diseased tissue, some of the cells containing resting sporangia.

PLATE XLII

a



b

Dry Rot of potato (*Fusarium caeruleum*) : (*a*) Symptoms on the tuber. (*b*) Photomicrograph of the spores showing chlamydospores.

PLATE XLIII

Root of a gooseberry bush enlaced with the rhizomorphs of the Honey Agaric (*Armillaria mellea*).

PLATE XLIV

1

2a

1. Verticillium Wilt or Sleepy Disease of tomato (*Verticillium albo-atrum*). A glass model of the conidial stage of the fungus greatly enlarged.
2. Stem and Fruit Rot of tomato (*Didymella Lycopersici*): (*a*) A severely affected stem of a mature plant.

Chapter Thirteen

Some Tomato Diseases

On many farms tomatoes are now grown as a "side-line," either as an outdoor crop or under glass. Where chitting houses have been built they are almost invariably used, after the removal of the potatoes, for the raising of tomatoes. An account of the more serious diseases of tomatoes, therefore, may be of interest to nurserymen and to some farmers.

As with other crops, so with tomatoes, disease is ascribed all too frequently solely to the activities of a particular organism, which, when found on the infected material, is allowed to take the full blame. In most instances, however, the fungus named represents only one aspect of the trouble. In practice the diseased condition can often only be explained as a complex in which the organism plays but a part. The requirements contributing to healthy growth and development of the plant are correct conditions of temperature, humidity and light, and a good soil in the right physical state—in short, favourable cultural conditions.

The grower, therefore, must always be on his guard to provide cultural conditions conducive to steady plant growth, and take care to avoid any check that may predispose the plants to pests and diseases, for disease usually appears to any serious extent only when cultural conditions are unfavourable. This principle applies particularly to many of the common diseases of tomatoes.

SEEDLING DISEASES. Damping-off and Foot Rot are widespread diseases that can be very destructive when sterilization of soil intended for raising seedlings is either not done or only imperfectly practised. Two fungi, *Phytophthora cryptogea* and *Phytophthora parasitica*, are mainly responsible, although species of *Pythium* are also sometimes concerned, more particularly *P. ultimum*. *Rhizoctonia Solani* is another fungus that may cause a Foot Rot of seedlings—the same

fungus (or a strain of it) causes Black Scurf of potatoes. Foot Rot due to *Rhizoctonia Solani* is more commonly encountered in the north of England.

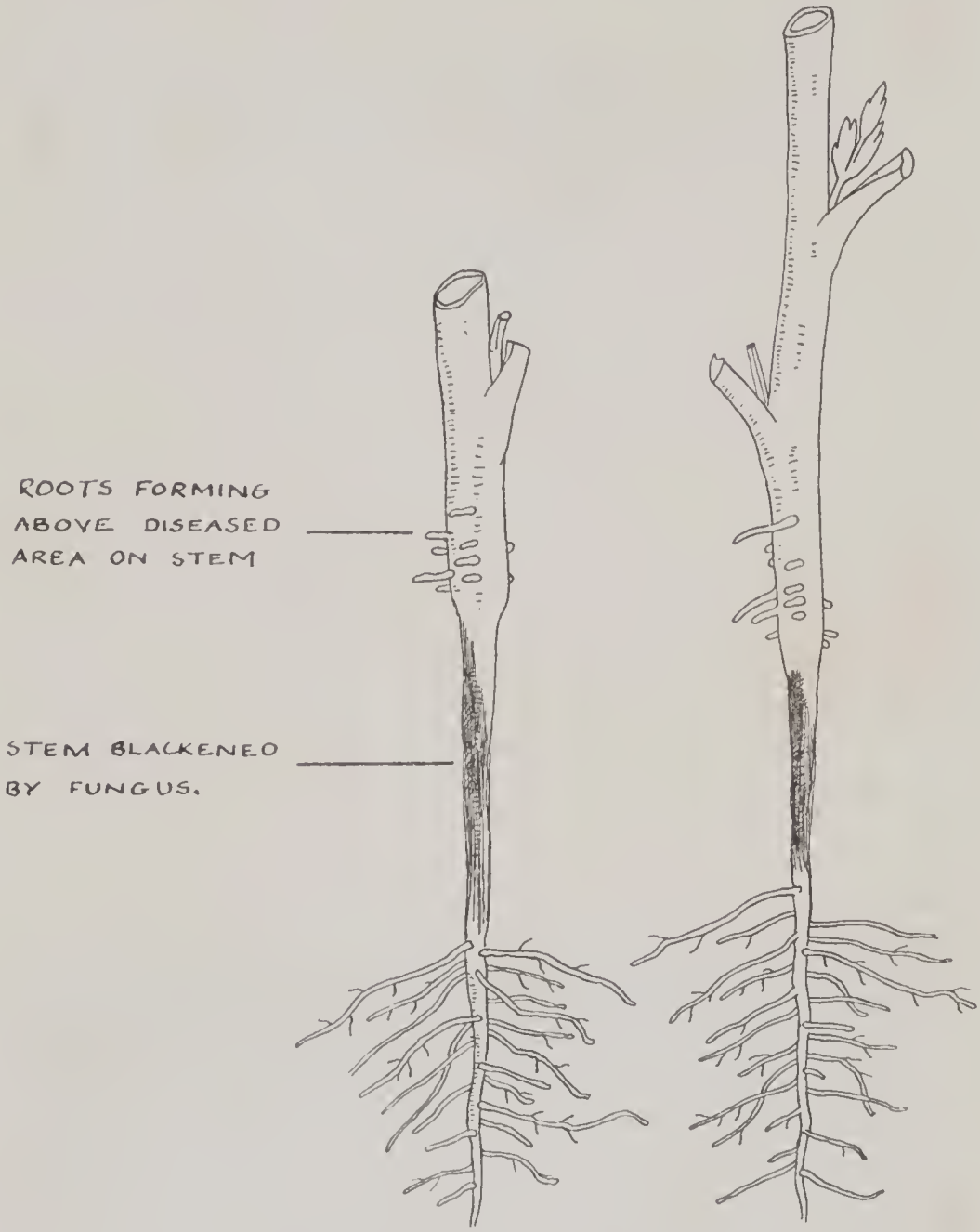


Fig. 4. Young tomato plants affected with Foot Rot.

When plants are affected with *Phytophthora* or *Pythium*, the symptoms usually appear at soil level where the tissues become browned, softened and eventually collapse. Rapid spread occurs from seedling to seedling and this is assisted by injudicious watering. *P. cryptogea*, *P. parasitica* and *Pythium*

species are all essentially water-fungi, and their spores are equipped with a mechanism to enable them to swim in the water-film on the surface of the soil. When they come into contact with the young stems they germinate and their germ tubes penetrate the tissues, upon which the fungus feeds. The stem then becomes soft and discoloured and the plant collapses and dies. *Phytophthora* and *Pythium* also produce resting spores (oospores) that can survive in débris from one season to the next. Both parasites can also live in water supplies, particularly when a large amount of organic matter is present.

Control Measures. When the disease appears in the propagating house, the boxes of seedlings may be watered with Cheshunt compound or cuprous oxide to check the spread and protect plants that are still healthy. The effect of the fungicide is to kill the zoospores. Plants that are already infected may be more speedily killed, but protection is afforded for those that are left. As high temperatures favour the disease the temperature should be carefully controlled. If possible, overcrowding of the seedlings should be avoided as this facilitates the spread of the disease and tends to maintain a humid atmosphere. Over-watering should be avoided.

The trouble will continue to appear in future years, however, unless further precautions are taken. The soil, pots, boxes, etc., may be contaminated and thus serve as a future source of disease. To prevent this the grower may have recourse to sterilization. For soils there is chemical, or preferably steam sterilization, and for pots and boxes, formalin may be used. The water supply, however, may also be contaminated. In 1921 Bewley and Buddin showed that water supplies on nurseries frequently contained the spores of pathogenic fungi, including those causing " damping-off " and Verticillium Wilt, especially where shallow wells near the glasshouses were used, or sluggish streams having a high content of organic matter. Although they suggested methods of sterilizing the water, the best measure is to ensure a safe source either from " companies' supply " or from deep artesian wells. Tanks for storage should have adequate protection from contamination, or the good achieved by selecting a safe supply is largely undone.

Above all, seedlings must be well established and grown without check to growth and development. This is most

important, not only in so far as seedling diseases are concerned, but also because of the bearing this has on the incidence of disease later in the life of the plant. Buck-Eye Rot of the fruit is a condition that may arise later in the season as a result of infection with *Phytophthora parasitica*, one of the fungi causing " damping-off." The symptoms are grey to reddish-brown patches on the fruit with darker brown, concentric rings. Infection arises from the soil by splashes and consequently the lower fruits are most frequently attacked.

Earlier reference has been made to *Rhizoctonia Solani* as being one cause of seedling mortality. Cheshunt compound has little effect on this disease and efficient soil sterilization and good cultural conditions are the best remedies. Sometimes this fungus also causes Wire Stem in older plants, and it is not unlikely that infection arises from potatoes, if the house has previously been used for chitting purposes.

BLACK DOT (*Colletotrichum atramentarium*). This is another disease that is almost invariably associated with some fault in cultivation. It usually occurs at the end of the season when cropping is almost finished, but if cultural conditions are unfavourable it may develop earlier when the plants are in full bearing. The usual sign of Black Dot (or Root Rot, as growers often call it) is the wilting of the foliage during the day with subsequent recovery at night. If the onset of the disease is severe, the cropping capacity is impaired and the plants may ultimately die. The softer and younger foliage at the top of the plant generally wilts first, the lower leaves being affected later.

If the roots of an affected plant are examined, it will be noticed that the outer skin or casing of the larger roots is dead and can often be pulled off like a hollow cylinder. On diseased roots minute, black bodies called sclerotia can be seen. These are the resting-bodies of the fungus *Colletotrichum atramentarium*, and it is by means of these that the fungus can persist in the soil. After a number of years the soil becomes heavily contaminated and, given the right circumstances, a heavy loss of plants may be incurred. Briefly, the conditions are those that are unfavourable to the plant and bring about a check in growth, such as cold, wet, compact soils, checks due to drying out (often following underflooding), the use

of cold water for watering, and (most frequently) allowing plants to become pot-bound before planting out.

Control Measures. The prevention of Black Dot lies in good cultivation and soil sterilization. When the plants are in full

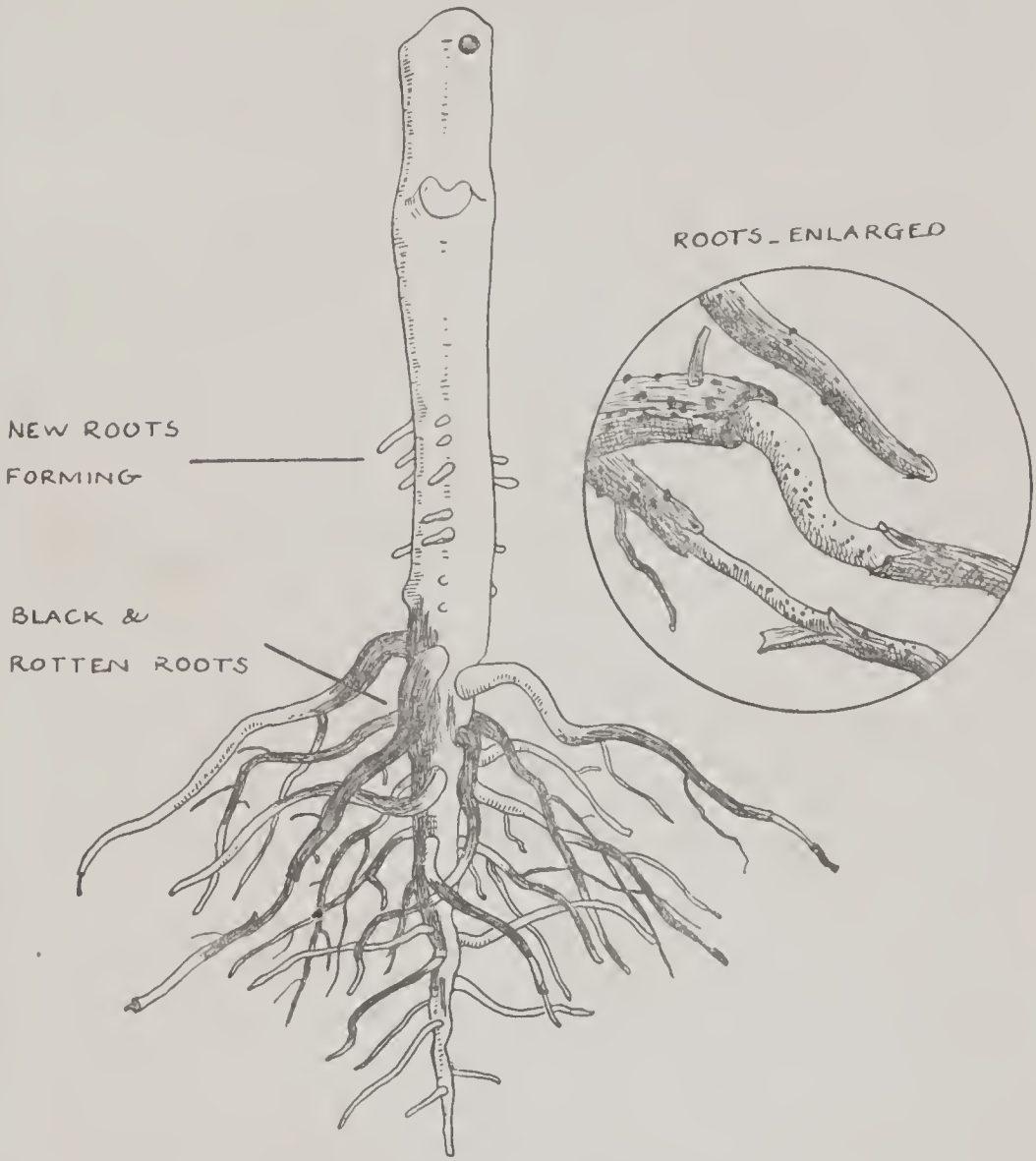


Fig. 5. A tomato plant with Black Dot disease—Root Rot (*Colletotrichum atramentarium*). Inset—roots with minute sclerotia and dead cortical tissue.

bearing, however, immediate action must be taken to prevent wilting. This is due to the reduced and impaired root system failing to make good the water lost from the leaves by transpiration. To reduce transpiration and subsequent wilting, houses should be closed down during the middle of the day,

and overhead damping should be practised to maintain a relatively humid atmosphere. The houses can also be shaded to reduce light intensity. The wilting of the plants having been checked, action can then be taken to stimulate the development of a new root system. This may be done by building up new soil around the bases of the plants or by mulching with peat which *should be kept moist*. After about 14 days a vigorous new rooting system will have formed and conditions may be relaxed to normal.

VERTICILLIUM WILT (*Verticillium albo-atrum*). Wilt or Sleepy Disease, another name by which it is known, is all too common and is reported from all parts of the country every year. Wilt starts about April, sometimes earlier, and reaches a peak about May or early June. The disease then usually dies down until late in the season when temperatures again become relatively low. Affected plants are generally stunted with relatively short internodes. When conditions are favourable to the fungus, the most typical symptom may be the sudden wilting of plants that previously appeared normal. A characteristic feature is that the wilt spreads *upwards*, the lower leaves being affected first. Recovery takes place at night, but the wilt recurs in the daytime. Under less favourable conditions the disease progresses more slowly, the lower leaves become blotchy and yellow and finally dry up, but without the plants actually wilting.

The vascular bundles or conducting strands are usually stained, and this can be seen when diseased stems are split lengthwise. The pathological symptom of wilting follows the mechanical blockage of the conducting vessels by the fungus and its secretion of a toxic substance. The discoloration can frequently be traced from the point of entry in the root to the upper parts of the plant. Infection originates from contaminated soil or adjacent diseased plants and takes place through the roots. "Hard" growth is generally more susceptible. The disease is associated with low temperature, hence its appearance early or late in the season.

Control Measures. In a growing crop, serious losses may result from a severe onset of the disease, and immediate action is necessary. The fungus is most favoured by temperatures

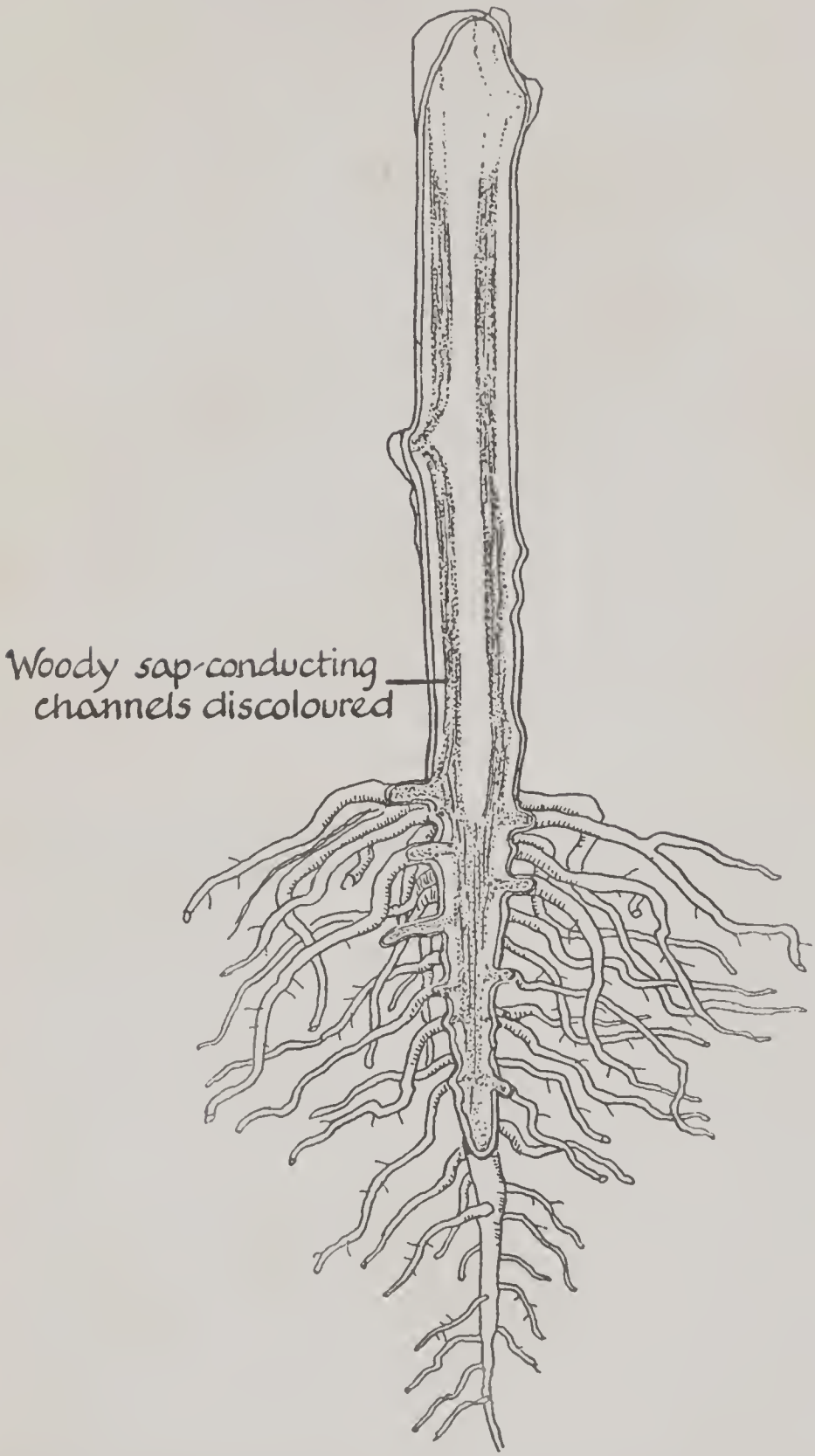


Fig. 6. Verticillium Wilt or Sleepy Disease of tomato (*Verticillium albo-atrum*). A diseased plant with the stem split lengthwise to show the discoloured vascular tissue.

between 60°F. and 75°F., but above 75°F. its spread is very slow. To check the fungus the temperature of the houses is raised to about 77°F. Steps are then taken to reduce transpiration as this prevents wilting and the rise of toxic secretion in the plant. This is done by overhead damping, reducing ventilation, *keeping the plants on the dry side* and shading the houses to reduce light intensity. The difference in control between this disease and Black Dot—in which normal watering may be continued—should be noted. Mulching peat or fresh soil round the plants will stimulate new root development, after which normal practice may gradually be resumed.

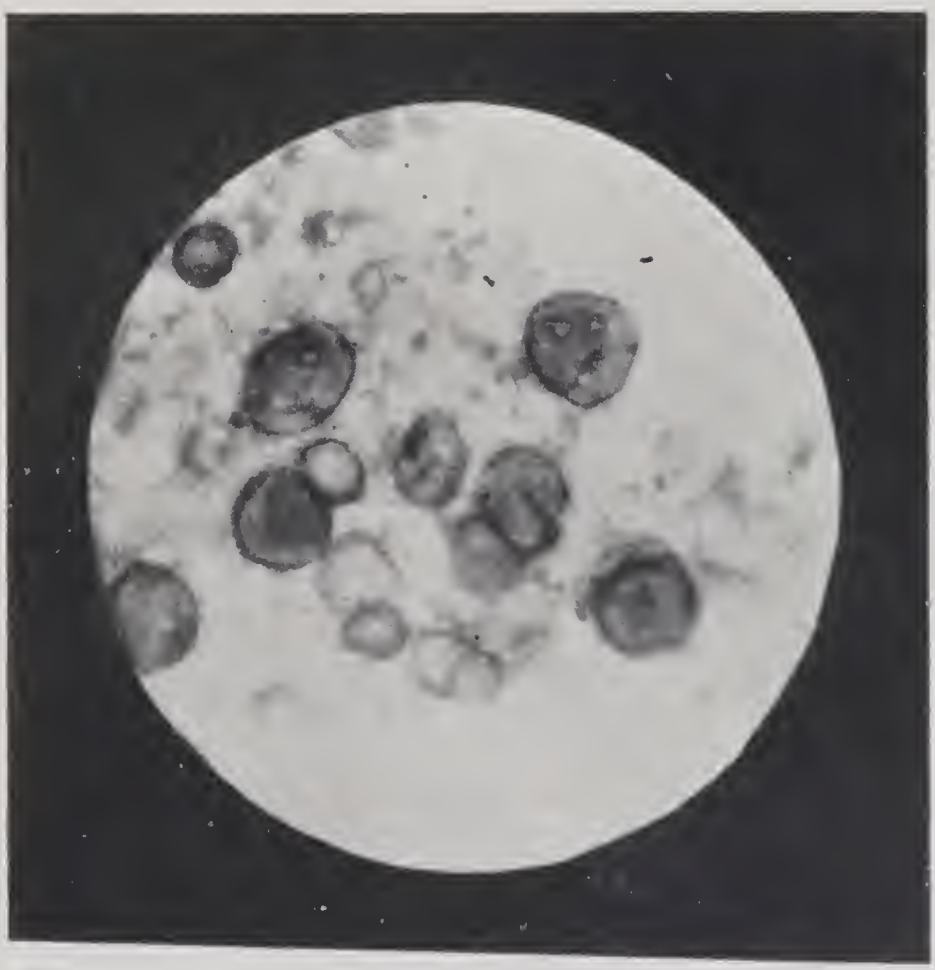
Partial soil sterilization at the end of the season, however, is the principal way of preventing the disease. Precautions must be taken to avoid recontamination, for the fungus spreads more rapidly in soil immediately after sterilization than when a fortnight or longer has elapsed. An additional precaution is to ensure a safe water supply.

There are many factors that render plants subject to infection—roots pot-bound at the time of planting, underflooding, and cold, hard, compact soils, etc. Wilt is frequently associated with Black Dot, as the same conditions favour both diseases. Other organisms occasionally causing root diseases followed by wilting are species of *Fusarium* and *Thielaviopsis basicola*. In contrast to Verticillium Wilt, however, Fusarium Wilt is relatively uncommon and is favoured by higher temperatures. Another species of *Verticillium* (*V. Dahliae*) may also cause Wilt but, although the control measures are similar for both species, *V. Dahliae* will grow at a higher temperature range, and is not so readily controlled by raising the temperature of the houses.

STEM AND FRUIT ROT (*Didymella Lycopersici*). In recent years Stem and Fruit Rot has been very prevalent and has caused much concern. It first became of serious importance to the tomato industry during the early part of the present century, reaching its maximum virulence about 1909. From then until about 1939, however, it was of no economic importance. Both indoor and outdoor crops are affected and the first symptom is the sudden wilting of individual plants as a result of the stem being girdled at, or just below, soil level. The lesions

PLATE XLV

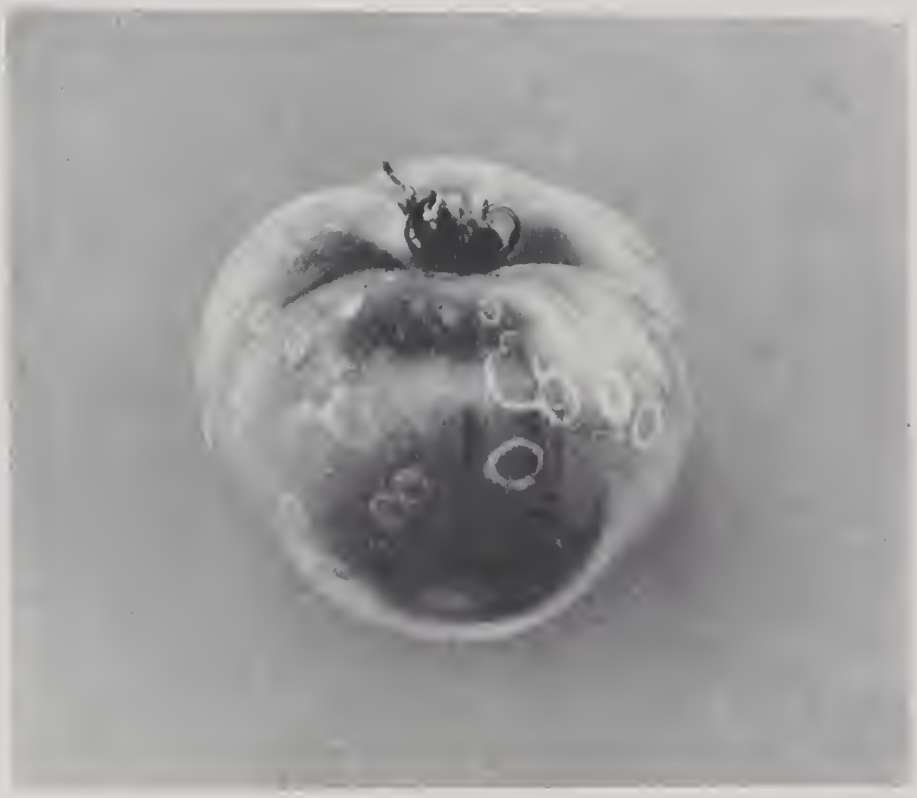
b



c

Stem and Fruit Rot of tomato (*Didymella Lycopersici*):
(*b*) A diseased fruit. (*c*) Photomicrograph of the pycnidia.

PLATE XLVI



1

2

1. Tomato fruit with spotting caused by the Grey Mould fungus (*Botrytis cinerea*). 2. A glass model of the Grey Mould fungus, greatly enlarged.

PLATE XLVII

1

2

1. Tomato fruits affected with the Potato Blight fungus (*Phytophthora infestans*). 2. Dry Set—a physiological disorder.

PLATE XLVIII

Black Rust of wheat (*Puccinia graminis*).

are generally dark-brown or black, and examination with a lens often shows them to be covered with large numbers of small, closely-crowded black pimples. These are the fruiting bodies of the fungus, the pycnidia, that consist of minute flasks containing conidia.

If the pycnidia are placed in a drop of water and examined under the microscope, the conidia are observed to be extruded in large quantities. They are embedded in mucilage in the form of tendrils that later disintegrate to disperse the spores in the water-drop. The spores are splashed by rain, or in course of watering, to the upper foliage or to neighbouring plants. Here they germinate, and the fungus gains entry through wounds, but infection can also take place when conditions are suitable, even in the absence of apparent wounds. Later in the season lesions are frequently found high up on the plants and occasionally on the leaves, especially on outdoor crops.

Considerable loss may also be incurred through Fruit Rot. The calyces are first infected and from there the fungus spreads into the fruit. If the calyx is removed at an early stage of infection a circular brown lesion can be seen and the flesh of the medulla immediately below is discoloured. The rot spreads and the whole fruit becomes black and rotten. Pycnidia are formed in great profusion and masses of spores extruded from them appear as a pinkish slime on the diseased parts of the fruits.

The disease can be carried on the seed, also on stakes, boxes, dead plants and particularly in contaminated soil. It can be spread during the season on boots and clothing of workers, on pruning knives and on hoses being dragged through the houses. Careless watering with excessive splashing encourages the spread of infection.

Control Measures. Tomato débris should be burnt, particularly if it is diseased. It must never be dug in or allowed to remain on the soil, for by means of such material the disease spreads and is perpetuated. After cropping, all plants should be cut off about nine inches above soil level, removed and burnt. In glasshouses that are situated sufficiently far from other valuable crops or from dwelling-houses, sulphur fumigation may first be carried out. This, besides killing free spores, dries the haulm and makes it easier to burn. The

houses should then be washed down thoroughly with 1 part formalin in 49 parts of water, and the surface soil saturated at the rate of 1 gal. per sq. yd. before removing and burning the roots. The soil is then dug thoroughly and sterilized with steam, formaldehyde or cresylic acid. All stakes, pots and boxes must be sterilized and the paths outside should also be sprayed. *Recommendations have been made by the Cheshunt Experimental Station that, two weeks previous to planting, the surface of the soil should again be sterilized by applying 1 part formalin in 49 parts of water at the rate of 1 gal. of the diluted mixture per sq. yd.

Only seed saved from healthy fruits or obtained from a reliable source should be sown, and care must be taken to plant out only healthy plants. Seed should not be saved from an outdoor crop unless absolutely necessary. Once the disease is noticed great care must be taken during watering to avoid splashing, and all unnecessary wounding during pruning must be avoided. Especially at the beginning of the season, before many plants are affected, all those showing signs of the disease should be lifted carefully together with the surrounding soil and burnt, in an endeavour to check further spread. Outdoor crops should be planted on clean land and should not follow tomatoes.

GREY MOULD (*Botrytis cinerea*). Under glass, and in the open in wet seasons, tomatoes are commonly attacked by the Grey Mould fungus, *Botrytis cinerea*, particularly where, owing to labour shortage, inexperienced workers are engaged on pruning and general management. The disease typically takes the form of light-brown lesions on the stems, sometimes completely girdling them, and generally starting from leaf scars, badly cut or torn sideshoots, or other wounds. These symptoms are frequently confused with those of Stem Rot, but in the latter the lesions are usually darker and pycnidia are often present. In moist atmospheres, *Botrytis* lesions are usually covered with a grey-brown felt of mycelium that gives off a cloud of dusty spores if shaken or blown. When examined under a microscope grape-like clusters of minute spores are seen. The fungus is a

*Experimental and Research Station, Cheshunt, Herts. Circulars Nos. 15 and 16.

facultative parasite ; it will grow on dead plant material as a saprophyte, but is capable then of spreading from dead to living tissues. Moist, stagnant air and badly-pruned plants, with ragged wounds and shoot and leaf "snags," are most conducive to the disease. In houses where these conditions apply the fruits often show symptoms of Botrytis Fruit Spot —ring-like markings that follow incipient infection at an earlier stage of growth. Care in pruning, the maintenance of adequate ventilation and strict nursery hygiene are, therefore, the primary measures of control.

BACTERIAL CANKER (*Corynebacterium michiganense*). Bacterial Canker was first recorded in this country in 1942 in East Sussex, since when it has been found in a number of scattered localities. The disease was previously known to occur in N. America (Grand Rapids Disease), parts of Europe, Australia and New Zealand. Early symptoms in the young plants are the wilting and withering of the edges of individual young leaflets, which bend downwards, turn yellow and then brown. If the stem is split lengthwise a characteristic yellow, light-brown or dark-brown streak may be seen just inside the woody cylinder of vascular strands, and sometimes running the whole length of the stem. Smears taken from this discoloured tissue and examined microscopically are seen to be swarming with the bacteria that are the cause of Bacterial Canker. In older plants the general symptoms are withering of the lower leaves and the appearance of yellowish-white streaks on the stems, the streaks later turning brown and developing into shrunken cracks or cankers. The pith may be disorganised, shrunken and discoloured. When a leaf-stalk is cut off transversely at its base, a ring or horseshoe of discoloured tissue is seen. The fruit may also become infected. The calyces dry up and, if one is removed, a brown stain is frequently observed —somewhat similar to that caused by *Didymella* fruit rot, but less regular and usually lighter in colour. On cutting the fruit the vascular strands show the characteristic yellow stain, from which the bacteria can be isolated.

Infection is transmitted during pruning and the organisms are splashed by rain or during watering. Diseased fruits resulting from splash infection show small brownish spots with

raised centres, each surrounded by a distinctive white halo. *Corynebacterium michiganense* is both seed- and soil-borne, and may also be carried in the compost. Precautions to be taken are the use of seed known to be free from infection and the thorough sterilization of contaminated soils. All diseased plants must be burnt.

LEAF MOULD (*Cladosporium fulvum*). Leaf Mould appears in most nurseries some time during the season, usually about June onwards, but on occasion starts as early as April or May. At times it occurs to a small extent on outdoor crops. The first symptoms appear as yellow patches on the upper sides of the leaves, these patches corresponding on the undersides with greyish areas of fungal growth that later turn purplish brown. This growth consists of mycelium bearing immense numbers of conidia, which provide the means of rapid spread under appropriate conditions. When severely infected the leaves die and become brown and shrivelled. A combination of soft growth with high temperature and humidity predisposes plants to attack. High night temperatures and damp foliage such as would follow overhead damping late in the day are particularly favourable to the disease.

Control Measures. Excessively high temperatures and humidity should be avoided and adequate ventilation maintained. In houses in which the plants are overcrowded ventilation can be assisted by judicious thinning of the foliage. The provision of ventilators in the ends of houses particularly subject to the trouble is often advantageous. Where the disease is persistently severe every year, protective fungicidal sprays may be applied to the foliage, and at the end of the season sulphur fumigation should be carried out. Varieties with a high degree of resistance are now being developed, among which is the Canadian variety Vetomold, and it may well be that the ultimate control of Leaf Mould will be by the use of resistant varieties.

BLIGHT (*Phytophthora infestans*). In some seasons when there is much rainfall in late summer and early autumn Blight causes much loss, particularly in the southern part of England, and more especially in the south-western counties.

The symptoms on the foliage and stems resemble those on potatoes, and brown, marbled areas appear on the green fruits, which may ultimately become completely brown and shrivelled. In very moist conditions, the fungus is seen as a white diffuse growth on the surface of the fruit.

Control Measures. These are similar to those adopted against Potato Blight, and involve the use of protective foliage sprays applied sufficiently frequently to ensure adequate protection for all new growth. Spray deposits on the fruit, however, may have to be wiped off. Diseased fruit and leaves should be removed and burnt.

VIRUS DISEASES. The more important virus diseases are described in a later chapter.

PHYSIOLOGICAL DISORDERS. There are a number of these, mostly concerned with the fruit. *Blossom End Rot* arises on strong-growing plants to which the water supply has been checked. Irregular watering or underflooding of the soil at the beginning of the season are frequent causes, and this may also lead to *Blossom Drop*. *Green Back* may arise from an inadequate supply of potash or exposure to high light intensities, and *Blotchy Ripening* from an incorrect balance of potash and nitrogen. Other disorders are *Sun Scald*, *Dry Set* (a condition due to imperfect pollination) and various symptoms associated with mineral deficiencies.

Chapter Fourteen

Diseases Spread by Air-borne Spores

The spores of many parasitic fungi are dispersed by wind, and this is an important factor in the spread of certain epidemic diseases of plants. Although air currents alone are often sufficient to detach the spores and carry them in a dry state, some are forcibly ejected into the air by the fungus itself, while others require to be detached by water before being carried in splashes or water droplets by wind-driven rain. There are many examples of diseases spread by air-borne spores, and some representative types will now be described, including the rusts of cereals, Potato Blight and the powdery and downy mildews. Of these, the rust diseases of cereals are of great world economic importance, and the fungi causing them have an intricate mode of life, some requiring two kinds of host to complete their life cycles. They are also obligate parasites and cannot exist apart from their hosts. The fungus causing Black Rust of cereals is an excellent example.

BLACK RUST (*Puccinia graminis*). In some countries, Black Rust is especially important, but in Britain it rarely gives cause for serious concern, for it is much less important than Yellow Rust (*Puccinia glumarum*). There are several distinct varieties of *P. graminis* that cannot be distinguished from one another by visual examination ; they differ, however, in their capacity to infect various cereals and grasses. The differences in pathogenicity are due to variations in their physiology.

There are several physiologic varieties, but three only are of serious economic importance, the others being confined mainly to grasses. One variety attacks wheat and barley, but not oats. Another attacks oats, but not wheat and barley. A third attacks rye.

In Britain, Black Rust of wheat generally appears late in the season, and in the Eastern Counties may often be observed about the first week in August. Long, reddish-brown pustules

develop as lines between the veins, chiefly on the sheaths and stems. These lesions contain masses of *uredospores* that are dispersed by wind, and are often a source of infection to crops over a wide area. Research* at the Dominion Laboratory of Plant Pathology at Winnipeg has shown that uredospores may frequently be found in the air at very great altitudes, and there is evidence that they may be air-borne as far as 700 miles from their point of origin.

The uredospores ensure the summer distribution of the disease, but they can only cause infection of the cereal host. They are brown, single-celled spores with relatively thin walls, and slightly spinous surface. They usually possess four germ pores—thin places in the spore wall through which the germ tubes emerge. Before germination can take place there must be a film of moisture over the surface of the leaf or stem, and in favourable conditions the spores may germinate within an hour or so. The germ tubes enter the plant tissue through the stomata. Within a few days an intercellular mycelium spreads in the tissue, drawing its nourishment from the cells by means of haustoria, and soon a fresh lesion or sorus is produced beneath the epidermis. Later the epidermis ruptures and a new crop of uredospores is liberated. The development of new uredospore pustules requires little more than a week from the time of infection, and the disease continues to spread during the season while the weather conditions remain suitable.

After a few weeks the reddish-brown lesions gradually become black, and teleutospores are produced. These are two-celled, a character that is typical for all members of the genus *Puccinia*. They are very dark-brown spores with smooth, thick walls, and are considerably thickened at the apex. These are " winter " spores and they remain until the following season on fragments of rusted straw, to which they are firmly attached, and where they ultimately germinate " in situ." They may also persist over several winters in a viable state, and they do not necessarily germinate in the spring following their production. When the teleutospore germinates, either cell may produce a *basidium*. This is a short, curved, hyphal outgrowth, generally three-septate, on

*Craigie. *Sci. Agric.* **25**, 6, 1945.

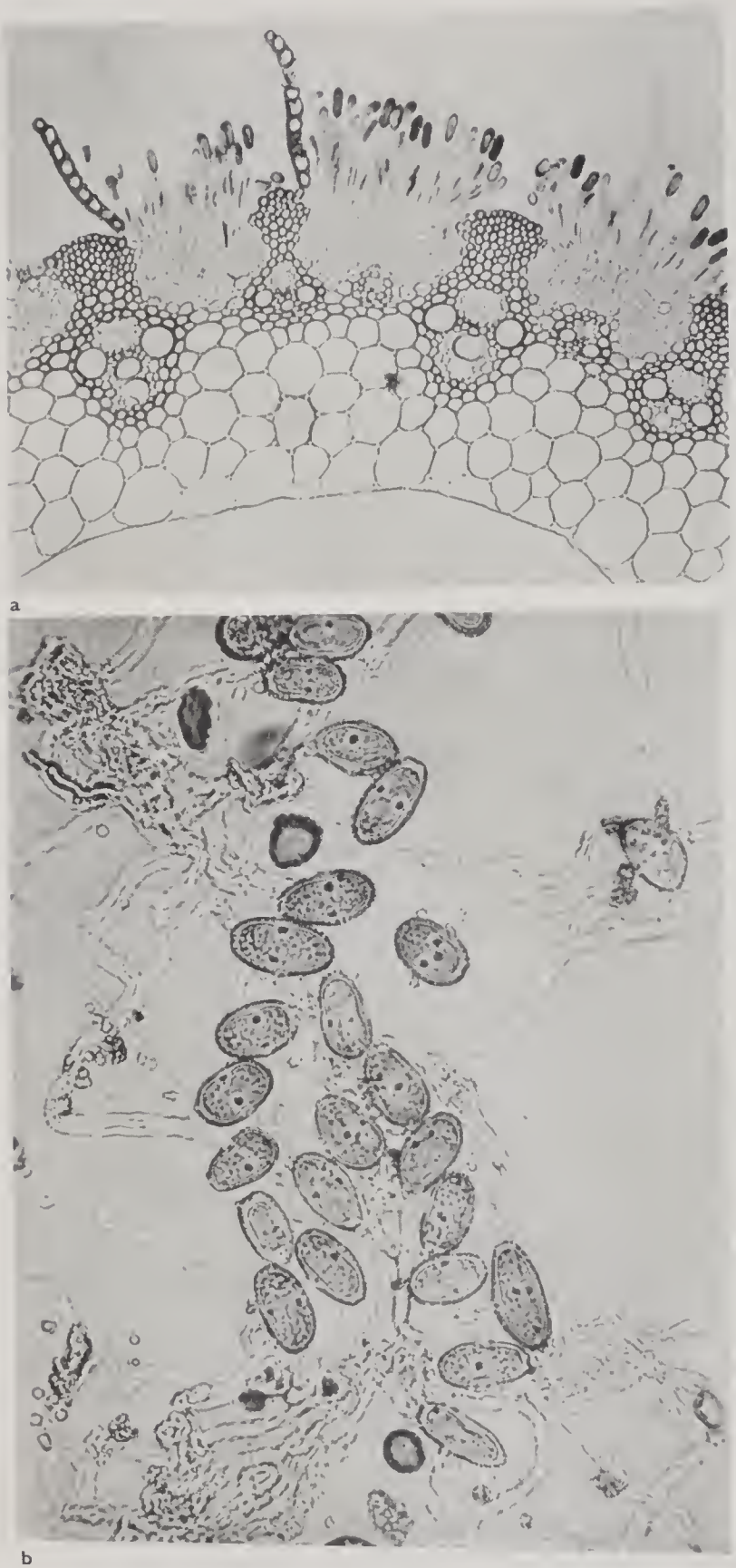
which *basidiospores* (sporidia) are borne. These are small, thin-walled spores borne on short, conical projections (sterigmata) arising, one from each cell, along the outer curve of the basidium. From each of the four cells a single sterigma and basidiospore is borne. It is this character that places the fungus in the class *Basidiomycetes*.

The basidiospores are not capable of infecting cereals, and can only infect the alternate host, the common barberry (*Berberis vulgaris*). They are discharged into the air and are carried by air currents. Unlike the uredospores, they are relatively short-lived, and the area over which they spread and still remain viable is relatively small. When a viable basidiospore falls on a barberry leaf, it germinates, penetrates the epidermis, and gives rise to the next phase of the life cycle. This can only take place, however, when a film of water covers the leaf. At the point of infection the mycelium develops within the tissues, and the affected part becomes thickened. The mycelium within the lesion gives rise on the upper side of the leaf to small flask-shaped organs embedded in the tissue. They are the *spermagonia* (pycnia), and contain minute spores known as *spermatia* (pycniospores) that are extruded in a honey-like liquid or nectar. Also projecting from the *ostiole* (the opening of the spermagonium) are bunches of hyphae, most of which are stiff and sterile, but some are flexuous and play an important part in the life history. On the lower side of the leaf the mycelium produces *aecidia* (aecia), cup-shaped structures in which yellow *aecidiospores* (aeciospores) are borne in parallel chains. These spores are produced successively from the base, and, when ripe, are shot off from the ends of the chains, and disseminated by air currents. In America, aecidiospores have been found* at altitudes up to 10,000 feet. The aecidiospores are incapable of infecting barberry, and can only infect the original cereal host.

Before 1927, the function of the spermagonium was not understood, but the development of spermatia was known to precede that of the aecidia. Aecidia were not produced, however, if the lesion on the barberry leaf had developed from infection by a single basidiospore. Craigie, in 1927, showed

* *J. Agric. Res.* 24, 599-606.

PLATE XLIX



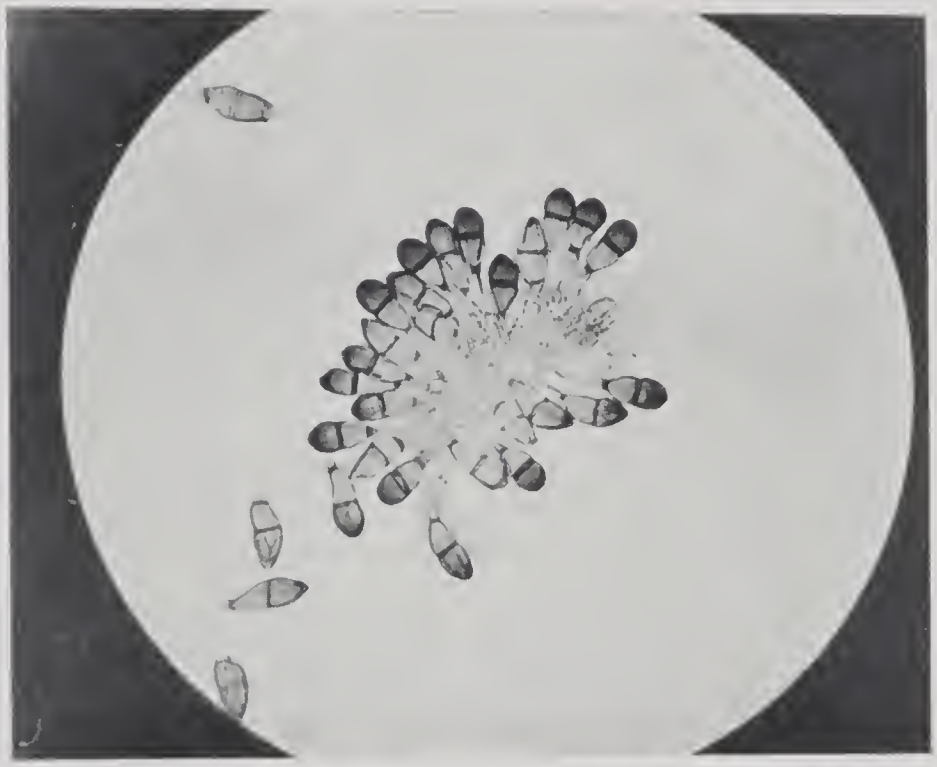
Black Rust of wheat (*Puccinia graminis*).

(*a*) Photomicrograph of uredospore pustules on wheat.

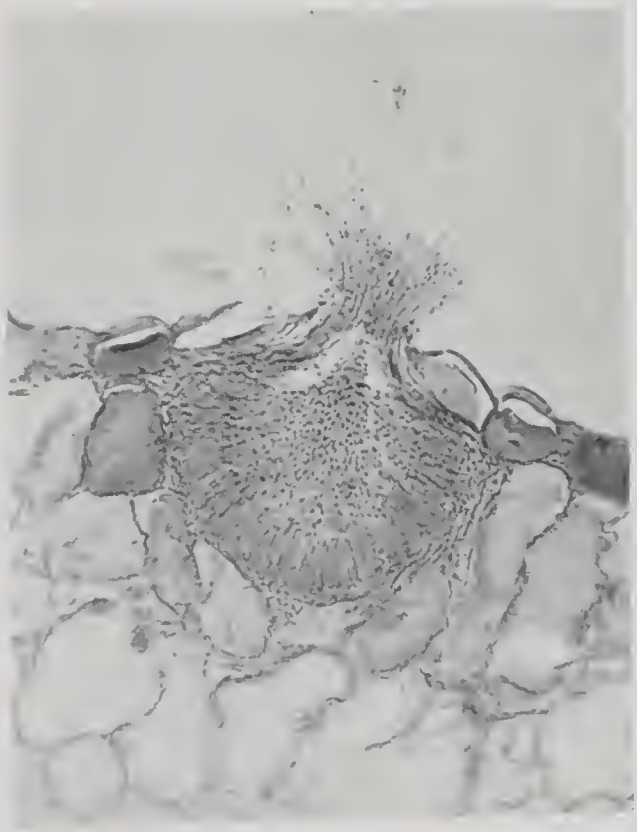
(*b*) Photomicrograph of germinating uredospores.

(By permission of the Dominion Laboratory of Plant Pathology, Winnipeg)

PLATE L



c

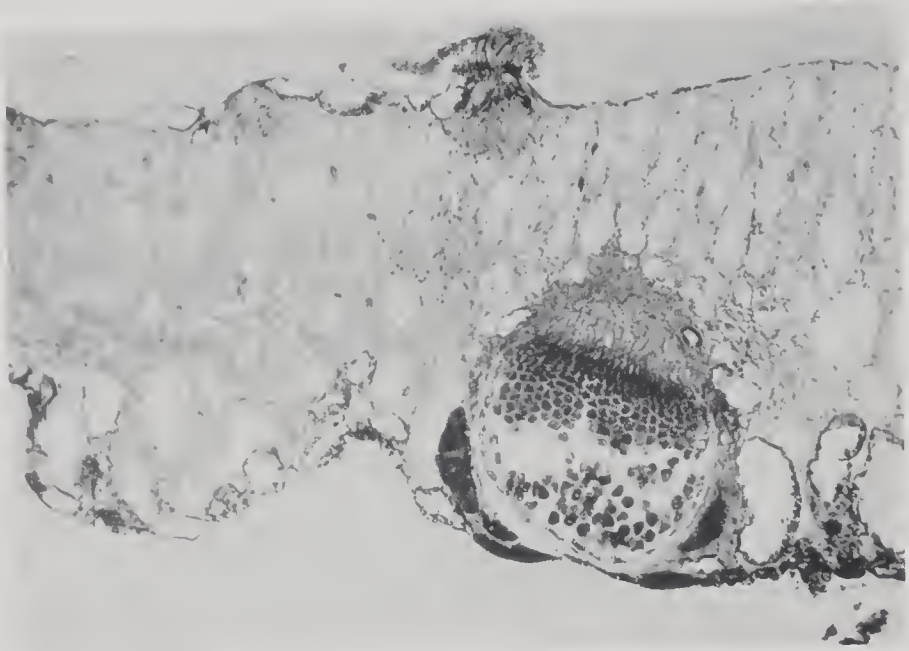


d

Black Rust of wheat (*Puccinia graminis*):
(*c*) Photomicrograph of teleutospores.
(*d*) Photomicrograph of a section through a spermagonium on the upper surface of a barberry leaf.

(By permission of the Dominion Laboratory of Plant Pathology, Winnipeg)

PLATE LI



e

f

Black Rust of wheat (*Puccinia graminis*):

(e) Photomicrograph of a section through a barberry leaf with a young aecidium on the lower surface, and spermagonia on the upper.

(f) Photomicrograph of the lower surface of a barberry leaf with a cluster of aecidia.

(By permission of the Dominion Laboratory of Plant Pathology Winnipeg)

PLATE LII

1 (By permission of the Dominion Laboratory of Plant Pathology, Winnipeg)

2

1. Aeroplane dusting a crop of wheat in the Prairie provinces of Canada.
2. American Gooseberry Mildew (*Sphaerotheca mors-uvae*).

that the basidiospores give rise to mycelium of two kinds with different sexual affinity, for convenience designated (+) and (—). When spermatia from a (+) lesion were placed on a spermagonium of a (—) lesion, fusion took place between the (+) spermatia and the flexuous *receptive hyphae* protruding from the (—) spermagonium. Similarly, this also occurred between (—) spermatia and (+) receptive hyphae. Fusion was later followed by the production of mature aecidia on the underside of the leaf. The transfer of spermatia from one spermagonium to another is greatly facilitated by flies that are attracted by the bright yellow colour of the pustules and the nectar secreted by the spermagonia. Fusion also frequently takes place when adjacent pustules of different sex merge to form compound pustules on the leaves.

It has been noted already that different varieties of Black Rust exist, differentiated only by their host reaction. Still further specialization within the rust varieties exists, however, for there are also *physiologic races* of the fungus that vary in the intensity with which they attack different varieties of their cereal host. There are known to be more than 150 distinct physiologic races of wheat Black Rust and, with the existence of a sexual stage in the life cycle of the fungus, it is possible for new physiologic races to arise as hybrids. The eradication of the barberry, therefore, is highly desirable, for it is by means of the sexual stage occurring on this host that hybridization of existing physiologic races may take place. Such hybrid races may be the means of breaking down resistance in new varieties of the cereal. It is the aim of the plant breeder to produce varieties resistant to as many as possible of the known physiologic races. The degree to which a given variety may be attacked, however, is dependent upon the presence of the particular physiologic races to which it is susceptible. Thus, a variety that is completely free from rust in one district may be attacked severely in another.

Control Measures. Apart from the breeding of resistant varieties, the control of Black Rust would appear to lie in the eradication of the alternate host, the common barberry. In some parts of the world, as in Northern Europe, where the winter temperatures are too cold for the survival of uredo-

spores, the barberry is the principal means of overwintering, and its eradication gives a measure of control.

Black Rust is also very common, however, in countries where the barberry is either absent, or too distant from the wheat-growing areas to play any part in perpetuating the disease. In Australia, where the alternate host is absent, the fungus carries over as uredospores that infect the young plants early in the following season. In India, where the wheat on the plains is a winter crop, the summer temperatures are too high for the survival of the uredospores, and infection arises from air-borne spores from the hill areas where wheat is cultivated during the summer months. In western Canada, the fungus does not overwinter in the uredospore stage, and the barberry has been eradicated since 1923. Here, rust infection occurs from uredospores carried by southerly winds from the northern Mississippi valley.

In Canada, and elsewhere, it has been found that losses due to rust may be minimised by growing early-maturing varieties that form grain sufficiently early to avoid the worst ravages of rust epidemics. Frequent large-scale dustings with sulphur have also been found to afford considerable protection from uredospore infection. In extensive areas, as in the prairies, aeroplanes have been used experimentally for this purpose, but as a general method of control sulphur dusting is not economic.

YELLOW RUST (*Puccinia glumarum*). Yellow Rust of cereals is of more concern in Britain than Black Rust, and in some seasons causes appreciable damage. Although more commonly found on wheat, distinct physiologic races occur on barley, rye and several grasses, including cocksfoot. Only the uredospore and teleutospore stages are known and, although the teleutospores are viable and produce basidiospores, these will not infect cereals. An aecidial stage has not been discovered. Perennation of the fungus is, therefore, dependent upon the survival of the uredospores from one season to the next.

In the spring, Yellow Rust may appear on the leaves and sheaths of young plants. The lesions are most conspicuous on the leaves of older plants, however, and are seen as cadmium-yellow pustules arranged mostly in parallel lines. Towards

the end of the season the rust may occur on the glumes and grains, and, on barley, may also infect the awns. Severely-attacked plants are reduced in vigour, and the leaves may wither and die prematurely, resulting in reduced yields and small, shrivelled grain. As the season progresses, the pustules contain two kinds of spore ; globoid, slightly spinous, lemon-yellow uredospores, and black, club-shaped teleutospores, with two cells and smooth walls.

Unlike the teleutospores of Black Rust, which must over-winter before germination, the teleutospores of *P. glumarum* can germinate in the autumn following their production. In the absence of an alternate host they appear to be without function, for they cannot cause infection of the cereal host. Although high summer temperatures may kill the uredospores, and reduce the incidence of the disease in subsequent months, the uredospores are capable of withstanding many degrees of frost. In autumn, the disease persists on self-sown plants amongst the stubble of a previously-infected crop, or round stack-bottoms. From here the uredospores are wind-borne to autumn-sown and spring-sown crops, on which the disease persists into the following summer.

Epidemic spread during the growing season is dependent upon suitable climatic conditions, and wind dispersal of the uredospores. The intensity of attack, however, also depends on the relative resistance of the variety grown. Varieties vary greatly in their reaction ; some are extremely susceptible, others markedly resistant. The fungus exists in a number of distinct physiologic races, however, and the resistance of a particular variety in one part of the country must not be taken to imply its resistance elsewhere, for the races are not necessarily uniformly distributed. Rivet wheat, and Little Joss in the adult stage, are very markedly resistant to Yellow Rust and could almost be described as immune. Other varieties vary in the degree to which they may be attacked, and certain of them, such as Desprez 80 and Wilma, are normally highly susceptible. The choice of a wheat variety, however, should be based primarily on soil texture and level of fertility, for the selection of a wheat unsuited to the local cultural conditions may result in losses greater than those anticipated from a possible rust attack.

Two cereal rust diseases only have been taken as examples of wind-borne parasites, but there are others of varying economic importance. Principal among these are Brown Rust of wheat (*Puccinia triticina*), alternate host, *Thalictrum* spp.; Brown Rust of barley (*Puccinia anomala*), alternate host, *Ornithogalum umbellatum*; Crown Rust of oats (*Puccinia coronata*), alternate host, *Rhamnus* spp., and Brown Rust of rye (*Puccinia dispersa*), alternate host, *Anchusa* spp.

POWDERY MILDEW OF CEREALS (*Erysiphe graminis*). The family *Erysiphaceae* also consists of parasitic fungi depending upon wind-borne spores for epidemic spread, and it comprises the true or powdery mildews. These are obligate parasites, nearly all of which produce a white, superficial mycelium over the surface of the host, and enter the epidermal cells and form haustoria within them. As with the rusts, it is the haustoria that enable the fungus to draw nourishment from the host.

The *Erysiphaceae* possess both an asexual and a sexual stage. The sexual stage consists of more or less spherical, thick-walled, closed bodies named cleistocarps (sometimes called perithecia), each containing one or more asci. Each ascus is a thin-walled, sac-like structure containing from two to eight ascospores. The cleistocarps possess appendages and the shape of these affords a partial means of identification. The asexual stage consists of colourless, unbranched, spore-bearing hyphae, from which oval, colourless conidia are abstricted in chains. The true or *powdery* mildews should not be confused with the *downy* mildews—which belong to the class *Phycomycetes*. Apart from wide morphological differences, the powdery mildews grow superficially, whereas the downy mildews penetrate deeply, and the chlorosis and death of the tissues is generally much more rapid.

Powdery Mildew (*Erysiphe graminis*) attacks cereals and grasses and, as with the rusts already described, exists in a number of highly-specialized physiologic races, each restricted to its own group of hosts. Varieties of cereals vary to some extent in their susceptibility to mildew, but none of the varieties commonly grown in Britain is immune, and the same variety may behave differently in different parts of the country.

On autumn-sown wheat, the first signs of the disease are often seen as early as February. The disease then appears as irregular patches of superficial, dingy-white mycelium on the sheaths and blades of the lower leaves, and large numbers of conidia are produced. These are carried away by wind to infect neighbouring crops and, if favourable weather conditions prevail, promote the epidemic spread of the disease. Between May and harvest mildew becomes general, but widespread infection is usually too late in the season to cause serious diminution of yield. The disease is most severe when dry conditions in spring and early summer follow a mild winter. The premature loss of foliage may then have an adverse effect, and result in badly-filled ears and shrivelled grain. In some seasons Powdery Mildew may also affect the ears, and these later become blackened by saprophytic moulds such as *Cladosporium herbarum*.

As harvest approaches, small black spore cases (cleistocarps), about the size of a small pin's head, are formed in large numbers among the patches of grey-brown mycelium. They bear rudimentary appendages by which they are attached to the host, and when mature contain from 9 to 30 asci, each usually containing eight ascospores. The cleistocarps are the resistant, overwintering stage of the fungus, and are present on the stubble, leaves and straw. The ascospores are forcibly discharged into the air at maturity, and are carried by wind to adjacent crops where they re-establish infection. The fungus also survives through the winter in the " mildew " stage on green tillers among the stubble, and on self-sown plants round stack-bottoms and elsewhere. From these sources, autumn- and spring-sown crops become infected by wind-borne conidia. Infection often becomes well-established on autumn-sown crops, and if spring crops are sown nearby they are more likely to be affected severely.

There are no practical methods of control other than the avoidance of conditions predisposing a crop to attack. Soft, dense growth is most susceptible, and consequently thick drilling and excessive nitrogenous manuring should be avoided. The future control of this disease probably lies in the production of resistant varieties.

Another very common powdery mildew with several physio-

logic races is *Erysiphe Polygoni*. This fungus attacks a wide range of crops including peas and various *Brassicae*. It is very common on swedes, turnips and kale, and these may appear white with it later in the season, especially in a dry summer. Other powdery mildews of economic importance are American Gooseberry Mildew (*Sphaerotheca mors-uvae*), Apple Mildew (*Podosphaera leucotricha*), Hop Mildew (*Sphaerotheca Humuli*) and many others. In all these the spores are air-borne.

Wind alone is not always sufficient to detach spores, and there are many examples of fungi in which they are set free by splashes of water, such as raindrops. For the epidemic spread of certain diseases, wind-driven rain is frequently most effective. The Potato Blight fungus is well adapted for the dispersal of its spores in this way.

POTATO BLIGHT (*Phytophthora infestans*). Although there are historical records of a potato disease, closely corresponding to Potato Blight, in Peru in 1550, the disease was not reported in Europe until 1840, and it was not until 1845 that it was noticed in Britain. During the following three years disastrous epidemics occurred throughout the British Isles: in Ireland, where the potato crop was the main source of food for an extremely backward peasant population, failure of the potato harvest caused famine and death.

Blight causes loss in two ways, by destroying the haulm prematurely and so reducing subsequent yield, and by infecting the tubers and causing them to rot. In Britain, the disease often appears in the coastal districts of the west country and Wales as early as the beginning of June, but usually it does not become general elsewhere until mid-July or early in August.

The first signs of attack are the appearance on the leaves, especially at the edges and tips, of pale, water-soaked spots, that soon become brownish-black. These lesions may spread rapidly and the whole haulm become blackened. Crops growing in low-lying and shaded places under moist conditions are most subject to attack. The greyish, halo-like margins that border the lesions on the under surface of the leaves consist of masses of delicate, branching hyphae bearing inverted, pear-shaped spore bodies (sporangiophores bearing sporangia). When conditions are warm and relatively dry, these spores

may germinate directly by putting out germ tubes, but when cool, moist weather prevails they liberate, when mature, up to sixteen small, free-swimming, biciliate zoospores. The cilia are hair-like appendages with which the zoospores can swim when liberated in a film of moisture.

The sporangia are readily detached by rain and they are most effectively distributed by wind-driven rain. A raindrop falling upon a mass of sporangiophores produces splashes containing large numbers of sporangia, and these may be scattered still further by subsequent raindrops. When a sporangium comes to rest on a leaf moist with dew or rain, it liberates zoospores that swim freely in the surface film of water. The zoospores settle on the leaf surface and produce germ tubes that penetrate the epidermis or enter through the stomata. At the point of infection the cells are soon killed, and the fungus then actively invades the surrounding tissue. Within a few hours, in favourable weather, a fresh crop of sporangia is produced round the advancing margin of the lesion. This rapid production of new sporangia ensures an abundant source of inoculum for extension of the disease. The maturation and spread of the sporangia, the liberation of zoospores and the initiation of infection, are greatly influenced by free moisture, temperature and humidity. There is, therefore, a close correlation between weather conditions and the incidence of Blight epidemics. This was first studied in Holland, and it was found that an epidemic could be forecast with much accuracy when the following combination of circumstances occurred :—

(1) Night temperatures below the dew point for at least 4 hours.

(2) Minimum temperature not less than 50°F.

(3) Mean cloudiness during the following 24 hours 0.8 or more.

(4) Rainfall during the following 24 hours at least 0.1 mm.

In south-west England, Beaumont found that a further condition, viz., relative humidity not less than 75 per cent. at 3.0 p.m., increased the accuracy of prediction. Beaumont later devised a simpler method for making local predictions

in Devon and Cornwall, and this necessitated the fulfilment of two requirements :—

(1) A minimum temperature of 50°F. or above.
(2) A relative humidity of 75 per cent. or more for at least 2 days.

Although conditions favourable to Blight may be expressed in such impersonal terms, the average farmer is very familiar with " Blight weather "—warm, dull days with a moisture-laden atmosphere. When such days are followed by cool nights and heavy dews, Blight may be expected.

After the foliage has become blighted, tuber-infection takes place from zoospores liberated by sporangia falling from diseased leaves. Exposed tubers are readily infected, while those below ground may be reached by zoospores washed by rain through cracks in the soil. There is no evidence that the mycelium grows down the haulm and along the stolons. Infection also takes place, at the time of lifting, if the haulm is still green, or partly green, with Blight present on it. A late attack on the foliage may be so slight as to pass unnoticed, and yet sufficient to cause heavy infection of the tubers. Potatoes so infected, although apparently sound at lifting time, will develop Blight in the clamp during the following 3 to 5 weeks. Blight does not cause loss by spreading from tuber to tuber in the clamp but, under poor storage conditions, injured tubers are subject to invasion by secondary organisms that cause soft rots, and these may spread and cause extensive damage. Infection by Blight alone, however, leads to a dry rot. The mycelium is mostly intercellular and causes death of the tissues, producing typical, foxy-red markings that extend into the flesh. The brown, discoloured areas are seen through the skin as darkened patches.

In southern and coastal districts, spraying with Bordeaux mixture (or similar protective sprays) should be a routine summer operation, but in other districts where Blight appears late, and is usually less severe, it may be sufficient to prevent tuber infection. Although spraying, if properly carried out, is rarely accompanied by injury to the foliage, this may occur in the immediate vicinity of large industrial areas, owing to the action that takes place between

PLATE LIII

1

2

(By permission of the Ministry of Agriculture and Fisheries)

1. Potato Blight (*Phytophthora infestans*).
2. Photomicrograph of the conidiophores and conidia of the Potato Blight fungus (*Phytophthora infestans*).

PLATE LIV

1

2

(By permission of the Ministry of Agriculture and Fisheries)

3

(By permission of the Ministry of Agriculture and Fisheries)

1. Section through a potato tuber infected with Blight.
2. Spraying a potato crop with a 5-lance, tractor-drawn spraying machine.
3. Applying a fungicidal dust to a Fenland potato crop.

PLATE LV

Clearing and cultivating the site of an old potato clamp.

PLATE LVI

1

1. Downy Mildew of sugar beet (*Peronospora Schachtii*).

2

2. A glass model, greatly enlarged, of a species of *Peronospora*.

the spray and the acid fumes in the atmosphere. Local advice, therefore, should be sought before spraying or dusting potatoes in such districts. Scorch may sometimes occur if spraying follows too soon after a crop has been severely buffeted and bruised by high winds. A delay of 48 hours before spraying is usually a sufficient safeguard. Mechanical injury by severe aphis infestation may also predispose a crop to spray injury.

Infection of the tubers is greatly reduced by good earthing up. A good depth of soil at the sides and tops of the ridges lessens the chance of the spores reaching the tubers, and also prevents greening. If the haulm dies completely so that the fungus is killed, and the crop is allowed to remain in the ground for a fortnight after the haulm is dead, the risk of infection at lifting time is negligible. If the haulm is still green with Blight spots, however, and it is not possible to delay lifting until the haulm has died naturally, it can either be destroyed prematurely by cutting, or by spraying with a dilute solution of sulphuric acid at least a week before lifting. As burning off with acid is a specialized operation entailing acid-resisting machines it is usually done by a contractor. Other more easily applied substances have been developed, but so far none is more effective than acid. The strength of the acid used depends on weather conditions, but it is usually applied as a 10-15 per cent. solution at the rate of 100 gallons per acre. Haulm destruction is especially useful in districts where Blight comes late in the season, and it is most advisable if the growth of the haulm has been prolonged by protective spraying, for it is then subject to late infection. Whenever possible lifting should be done during dry weather and the tubers clamped in good conditions.

There is need for greater care in the disposal of blighted tubers. It is a bad practice to leave " blights " lying in the field to produce volunteer plants, and so harbour the disease. Frequently the first outbreaks of Blight are found near the sites of old potato clamps, for it is there, at the time of riddling, that the majority of diseased tubers are discarded. When clamps are opened " blights " should not be left lying about. They should be sorted over, the best of them boiled and used for pig-feeding and the remainder burnt or buried deeply.

As soon as possible the site should be ploughed and cultivated, and not left for a wilderness of volunteer plants to arise from discarded potatoes. Areas of land that have been occupied by clamps, moreover, are usually too valuable to waste by leaving them without a crop.

Care should be taken not to plant tubers showing signs of infection, for these may give rise to diseased shoots and so cause an early outbreak of Blight.

As might be expected, the plant breeder is attempting to control Blight by producing resistant varieties. This work has been attended by much success, but the problem is complicated by the existence of distinct physiologic races of the fungus. As yet, commercial varieties are not available.

DOWNY MILDEW OF SUGAR BEET (*Peronospora Schachtii*). The *Peronosporales* contain many parasitic fungi causing diseases of economic importance, including the Downy Mildews, all of which, like *Phytophthora infestans*, are favoured by wet conditions. Unlike the true, or Powdery Mildews, that grow superficially on the host, the Downy Mildews generally produce intercellular, non-septate mycelium. The dichotomously branched, aerial conidiophores bearing conidia singly at the tips of the branches form one of the most distinguishing features. *Peronospora Schachtii*, the cause of Downy Mildew of sugar beet, and *Peronospora destructor*, causing Downy Mildew of onion, are two of considerable importance.

Peronospora Schachtii affects sugar beet, red beet, and mangolds. The disease is usually seen on " root " crops about June or July, attacking the young heart leaves and causing them to become pale green, thickened and distorted. The leaves are often wrinkled, with a backward curling of the margins, and the undersides are covered with a lilac-grey, downy, felt-like mass of conidiophores bearing conidia. These germinate directly to produce germ tubes, unlike *Phytophthora* in which zoospores are usually produced on germination. Resting bodies (oospores) are also formed but, in this particular species, it is thought that they play little part in the economic spread of the disease.

During warm, humid weather, Downy Mildew may be

severe, resulting in a smaller yield and sugar content in root crops, and markedly reduced yield in seed crops.

Control Measures. Fortunately, severe attacks rarely occur in root crops, unless these are infected early in the season by spores blown from adjacent or nearby seed crops. Similarly, severe attacks on seed crops usually result from infection the previous autumn by spores originating from nearby root crops. Plants being grown for seed should be separated, therefore, as far as possible from root crops, and be situated so that spores will not be carried from the roots to the seed plants by prevailing winds.

Although fungi are often the agents of disease, and may be carried on the seed, in the soil or in the air, there are many disorders for which they are not responsible. Some of these are due to faulty nutrition, others to virus diseases.

Chapter Fifteen

Nutritional Disorders

For normal plant growth a number of essential elements must be present in the soil, some of which are required in larger amounts than others. They are usually referred to as " major," and " minor " or " trace " elements respectively, and are so named for the amounts in which they are necessary in the soil, rather than for their relative importance to normal plant functions. For this reason the term " trace " is to be preferred to " minor." Because of its intermediate position iron, although generally classed as a major element, is often regarded as a trace element in the consideration of field problems. The elements are classed as follows :—

Major : *Nitrogen*, *phosphorus*, *potassium*, *calcium*, *sulphur* and *magnesium*.

Trace : *Iron*, *boron*, *manganese*, *zinc*, *copper* and *molybdenum*.

Although these elements may be present in the soil it does not follow that the plant can absorb them. Its capacity to do so depends upon its environment. The relative quantities of plant nutrients in the soil must be balanced to suit the needs of the plant, and the soil must be in a correct physical condition, at a suitable temperature, with adequate water and aeration. The temperature and humidity of the air must also be favourable, with light intensities of periodic duration suitable for the particular plant. Abnormal variations in these environmental conditions can result in alterations in mineral requirements and may induce symptoms of deficiencies that would not normally arise. An example is the greater need for available nitrogen in high light intensities than in shade. Plants that show pronounced symptoms of " nitrogen starvation " in high light intensity may develop the normal green colour of the foliage again on reducing the light by shading.

Both major and trace elements are adequate in most soils, but in recently-reclaimed derelict land they are frequently ill-

proportioned. Abnormal conditions can also arise after long periods of cultivation if the manurial and cropping policies have not been planned with due regard to soil requirements. In such circumstances, symptoms of a deficiency of some essential element may occur owing to excess of others. Apart from the essential elements listed, there are others that are not essential but nevertheless produce beneficial effects on the growth of some plants. Among these are chlorine, silicon and sodium. Plant ash has also been found to contain elements that, as far as can be ascertained, are not essential. Lithium* is found in the ash of some plants and, although it is not necessary for growth, its presence in celery has been linked with reduced susceptibility to Leaf Spot (*Septoria Apii-graveolentis*). It has also been shown to induce slightly increased resistance in young wheat plants to Mildew (*Erysiphe graminis*) and Brown Rust (*Puccinia triticina*). Lithium in the soil in more than minute amounts, however, is toxic to plant growth.

It must be emphasised that, although some elements found in plant ash are only accessory, the major and trace elements are vitally necessary for healthy growth. These must be present in the soil in forms available to the plant, and the environmental conditions must be such as to enable them to be absorbed. If these conditions are not wholly satisfied, pathological symptoms commonly known as " deficiency diseases " may arise. A full account of these, with illustrations, is given by Wallace, of the Long Ashton Research Station, in *The Diagnosis of Mineral Deficiencies in Plants*, a colour atlas and guide, published in 1944 by H.M. Stationery Office. Reference has been made to this publication in compiling the following brief account of the symptoms of some of the more important of the nutritional disorders.

NITROGEN. Nitrogen starvation is of fairly common occurrence. Most plants in this condition show limited development of both shoot and root systems and the growth tends to be thin and drawn ; early spring growth is often much retarded. Leaves are reduced in size and are generally paler green than normal, sometimes developing yellow,

* Kent, N. L. (1941). *Ann. Appl. Biol.* **28**, 189.

reddish and orange tints. Older leaves are usually first affected.

Cereals suffering from nitrogen deficiency tiller poorly, are pale green and may be chlorotic. Forage crops such as kale and cabbage are severely affected by nitrogen deficiency ; young leaves are pale green, while older leaves develop orange, red and purple tints, often followed by premature defoliation. Symptoms in mangold and beet are pale-green leaves and stunted growth.

Nitrogen assists in the production of healthy, dark-green foliage, and for this reason applications of nitrogenous dressings in spring, when supplies of available nitrogen in the soil are low, is often of great value. Care must be exercised, however, not to apply an excess, for this may promote soft growth susceptible to fungal attack. Severe attacks of Mildew (*Erysiphe graminis*) on wheat frequently follow excessive nitrogenous manuring. Excessive applications of one major element such as nitrogen may also result in relative deficiencies in other essential elements.

PHOSPHORUS. Most soils respond to applications of phosphatic fertilizers by giving improved yields, although few are sufficiently lacking in this plant food to induce symptoms of acute deficiency. Effects of phosphorus deficiency are very similar in many respects to those of nitrogen starvation. Growth both above and below ground is limited, the plants are thin and drawn, leaves are small and defoliation occurs prematurely. Lateral shoots are few and lateral buds may die or fail to develop. Leaf colorations due to phosphorus deficiency are, however, more distinctive. Leaves tend to become a bluish-green and lack lustre. The tints are more purple than yellow or red, and in some plants the leaves show a dull bronzing. The leaf margins may also develop a scorched appearance.

Potatoes show these symptoms markedly, while beet and mangold leaves generally remain almost normal but without lustre and slightly bronzed. Although purple tints are commonly shown by the foliage of plants growing in phosphorus-deficient soils there are many other conditions that produce similar effects. It is unwise, therefore, to ascribe a set of

symptoms to a particular cause until other likely factors have been considered. When doubt exists as to the sufficiency of a major element a soil sample should be taken and an analysis obtained.

POTASSIUM. Plants vary in their potash requirements and, as this element appears to be associated intimately with the ability of the plant to produce carbohydrates, crops that store quantities of carbohydrates in tubers and other organs are very severely affected by a deficiency. The production of fruit and grain is also often greatly impaired. Growth of both roots and shoots is restricted, stems develop short internodes and the foliage of most plants turns bluish-green, sometimes with slight interveinal chlorosis. There is a pronounced tendency for broad-leaved crops to show scorched leaf margins, although this symptom is not peculiar to potash deficiency and may sometimes arise from other causes.

Cereals, especially barley, develop poor, dwarfed plants, which tiller extensively in contrast to those starved of nitrogen or phosphorus, but produce few heads with few grains of small size. The leaves are blue-green or slightly chlorotic, with browning of the tips and margins. Potash deficiency severely affects potatoes, and the plants are dwarfed, the leaves lack lustre and are blue-green, with scorching of the margins and tips. Slight interveinal chlorosis may also be apparent. The upper surface of the foliage has a characteristic bronzed appearance while necrotic spots develop on the undersides. Premature death of the haulm may ultimately result and the crop yields are poor. Clover, besides showing marginal browning, also develops necrotic spotting of the leaves. In general, potash greatly assists in maintaining the health of the plant and in supporting natural resistance to disease.

CALCIUM. Young leaves and growing tips are most affected by lack of calcium, and the root system of plants suffering from deficiency of this element is invariably poorly developed and restricted. Leaf margins tend to be chlorotic and later become scorched. See also *Iron*, p.124.

In potatoes, the tips of the foliage of affected plants are characteristically chlorotic with the small leaves rolled inwards

parallel with the mid-rib. Tuber formation is almost completely arrested. Foliage symptoms may occasionally be mistaken for those associated with Stem Canker (*Corticium Solani*). It does not necessarily follow that sour soils are deficient in calcium, for plants may grow in acid soils without showing symptoms of calcium deficiency. There are disorders, however, such as Stringy Root of sugar beet and mangolds, that are associated with sour soils, and that respond to judicious applications of lime. In such instances, the effect is probably one of corrected acidity rather than the supplementing of available calcium.

MAGNESIUM. Symptoms of magnesium deficiency have been studied chiefly in fruit plantations and glasshouse crops, and the extent to which field crops are affected is not generally known, but magnesium deficiency does not appear to be a serious factor. Experimental work has shown that symptoms vary greatly in different crops, and their diversity renders a general description difficult. The foliage is most affected and symptoms develop first in the oldest leaves and successively affect the younger ones. Magnesium is a constituent of chlorophyll and deficiency of it interferes with normal chlorophyll production. Chlorosis is, therefore, a very common symptom, but many and varied tints of considerable brilliance may subsequently develop. Defoliation is usually premature. Tomato leaves show a noticeable form of interveinal chlorosis with retention of the green coloration at the margins. Interveinal necrosis generally follows, and the leaves are shed.

The lighter, sandy soils have a greater tendency to be deficient in magnesium. Excessive applications of potash on soils naturally low in magnesium are apt to induce symptoms of magnesium deficiency. This occasionally happens in tomato-houses in this country.

IRON. Iron deficiency most commonly affects fruit; cereals and other farm crops and vegetables are relatively insensitive. As with magnesium, iron is associated with chlorophyll production, and the most typical symptom is severe and frequently complete chlorosis of the leaves. This

is usually more marked on the younger growth in contrast with magnesium chlorosis, which first appears on the older leaves. Defoliation later takes place. Chlorosis due to iron deficiency is almost invariably associated with excessive lime content in the soil, and for this reason it is usually referred to as lime-induced chlorosis. Cabbage and related crops all show an irregular chlorotic effect or " marbling " which is similar to, and may easily be confused with, manganese deficiency. Cereals are rarely affected by deficiency of iron in the soil.

MANGANESE. Manganese-deficient areas are not uncommon in the Eastern Counties of England, and are generally associated with alkaline peat formations, the type of peat often referred to as " shell peat " by reason of the number of mollusc shells found in it. Chlorosis of the leaves in various forms is one of the most frequent symptoms of manganese deficiency. Characteristic symptoms in potatoes are the paling of the leaves on the tips of the shoots and the lack of natural lustre. These leaves tend to roll inwards. Small brownish-black spots may be seen along the veins, most frequently on the pale young leaves. Symptoms of manganese deficiency vary with different crops, and give rise to several well-defined " diseases."

Sugar Beet—*Speckled Yellows.* This disorder, due to manganese deficiency and affecting sugar beet and mangolds, can easily be confused with Mosaic due to virus infection. In Speckled Yellows, however, the leaves are more erect in habit and, owing to the upward rolling of the margins, they appear to be more triangular in shape. The interveinal tissue becomes irregularly chlorotic and shows a distinct mottling or mosaic effect, from which the disease gets its name. Brownish spots, which later turn necrotic and fall out, may appear in the interveinal areas of the leaves.

Oats—*Grey Leaf.* Oats are especially sensitive to shortage of manganese and produce distinct pathological symptoms known as Grey Leaf. Root development is poor, and greyish streaks or specks occur on the older leaves of the young plants early in the year, mostly on the basal portions. Later in the season, the streaks coalesce and the tissue turns brown and necrotic. Severely affected plants die or, if they recover,

produce few heads and little or no grain. Some confusion occasionally arises over the symptoms, which can be mistaken for Leaf Spot (*Helminthosporium Avenae*).

Peas—*Marsh Spot.* Pea plants affected with manganese deficiency usually appear quite healthy, although a chlorotic condition may appear if the deficiency is acute. The principal symptom by which the disease is known is seen if the seed coat is removed and the two cotyledons are divided. A brown marking is present on the inner flat surfaces, and may be a small speck, or larger and circular. The spot generally appears slightly water-soaked. When the deficiency is acute the centre of the seed may be completely collapsed and hollowed out.

Control. The deficiency diseases that are associated with lack of manganese may sometimes be largely prevented by the application of manganese sulphate to the soil or, more effectively, by spraying the plants. On severely-affected land about $\frac{1}{4}$ cwt. per acre applied to the soil at the time of seeding has sometimes proved satisfactory. Alternatively, when facilities for spraying are available, a quicker and more certain response can be obtained by spraying the crops with a solution of manganese sulphate, using, in severe cases, up to 10 lb. per acre in 100 gallons of water. For the control of Marsh Spot of peas, spraying is the only method that will give any satisfactory result and it is best carried out during flowering.

BORON. The boron content of soils varies, and its availability is closely linked with soil water content and lime status. Drought conditions, high alkalinity (such as occurs with excess of lime in the soil), and sandy, gravelly soils of poor water-holding capacity reduce the availability of boron and aggravate the symptoms of its deficiency. Deficiency of boron is the cause of several nutritional disorders ; the symptoms are very diverse and on some plants the effects may be severe. Examples are Heart and Dry Rot of sugar beet and mangolds, Brown Heart or Raan of swedes and turnips, Cracked Stem of celery and Browning or Hollow Stem of cauliflower. In each of these diseases it is the heart or crown that is commonly affected.

Sugar Beet—*Heart and Dry Rot.* Early symptoms of Heart Rot are very typical. The innermost young leaves are weakly developed and ultimately die, and rotting of the crown follows. In older plants the outer leaves show a wilted condition and may become chlorotic and wither. There is a tendency in mangolds for rotting to commence at the side of the root, but apart from this the symptoms are essentially similar. Affected roots when sliced through lengthwise often show discoloration of the vascular tissues as well as the hollow, rotted crown. Heart Rot is often confused with the late effects of Downy Mildew (*Peronospora Schachtii*). A great similarity between Heart Rot and Downy Mildew exists in the later stages, as, in both, the death of the central leaves may be followed by a crown rot. When doubt exists as to the correct diagnosis, expert advice should be sought.

Swede and Turnip—*Brown Heart* or *Raan.* Turnips and swedes may show no external indications of boron deficiency, and it is only upon cutting the roots that the condition known as Brown Heart or Raan can be seen. Patches of light brown, water-soaked tissue in the central portions of the root are then to be observed. Affected roots are inclined to be woody and unpalatable.

Control. Deficiency diseases due to the non-availability of boron may be controlled by applying to the soil compounds containing it, or by correcting the soil conditions to make available the boron already present. Direct applications are generally made in the form of borax at the rate of about 20 lb. per acre. The borax is often incorporated with fertilizers, e.g., boronated basic slag. On land subject to boron deficiency, care should be exercised in the application of lime as an excess accentuates the deficiency. Deep-rooting plants will often show less marked symptoms than shallow-rooted ones that are subject to drying out.

GENERAL REMARKS. This brief account of nutritional disorders arising from the deficiency of certain essential elements serves to illustrate their many and diverse symptoms, and indicates how difficult it is to identify them with certainty. Although it is possible to identify some of these disorders at sight, there remains the possibility that similar symptoms may

be due to other causes. It is for this reason that a farmer or grower would be well advised to consult his county or provincial advisory officer before applying remedial measures. Soil samples taken by the county officer will show on analysis whether the trouble is associated with deficiency of a major element such as potassium or phosphorus, but, where a trace element is suspected of being deficient, a spectrographic analysis or tissue test of foliage from affected and unaffected plants may be necessary before the cause can be determined.

Application of control measures requires great care. Trace elements such as boron can be very toxic in excess. Excessive application of some elements can also accentuate deficiencies of others ; thus excessive dressings of lime, such as are frequently applied against Club Root (*Plasmodiophora Brassicae*), may induce symptoms of manganese and/or boron deficiency by rendering these elements unavailable. Pathological disturbances to plants due to unbalanced nutrition are often complex, and it cannot be emphasised too strongly that diagnosis, or the assignment of causes to symptoms, requires much experience.

Chapter Sixteen

Virus Diseases

Viruses are known to attack all forms of life. They are agents of disease in a large number of plants, including many of considerable importance, and their symptoms have long been known. A condition of tulip flowers, now recognised to be a disease caused by virus, was described in the latter part of the sixteenth century and figured in works of art some fifty years later. The disease is called " break " or " breaking " because of the " broken " colour developing in otherwise " self-coloured " varieties. Such stocks in the past sold for high prices.

Towards the end of the eighteenth century, degeneration and loss of productiveness in potato crops growing in lowland areas in this country were also noted, and began to cause much concern. Continuous vegetative propagation was at first held to be responsible, but this degeneracy is known now to be due to virus infection.

The main character of virus diseases is that the active principle or virus is systemic and may be found in all parts of the plant, but it is rarely found in the seed and virus diseases are seldom transmitted in this way. Symptoms usually appear throughout the plant, although they show most strongly in the growing parts and the young leaves, and herbaceous plants are more commonly affected than are trees and other woody plants. The main symptoms of most plant virus diseases are associated with general disturbances following interference with the normal mechanism controlling chlorophyll production. Typical symptoms frequently take the form of mosaic or mottling of the foliage, chlorosis, streaks on foliage and stems, and sometimes necrosis or death of the tissues. These disturbances may also be followed by dwarfing or distortion of the affected plants. Always the disease is transmissible from diseased to healthy plants, although the manner of transmission varies.

Although the symptoms of virus diseases have been familiar

for many years, it is only since the end of the nineteenth century that the causal agents have been shown to be *ultra-microscopic infective principles* present in the sap and *capable of passing through bacteria-proof filters*. Hitherto much doubt and speculation have existed as to whether virus particles are living organisms, and they were regarded formerly as a transitional stage between the dead and the living—inanimate, yet possessing the properties of life, chiefly the ability to multiply in the cells of the host. In recent years, however, certain of the viruses have been isolated, purified by chemical means and photographed with the aid of the electron microscope. Those plant viruses that have been purified have been found to be protein in nature, with a well-defined chemical composition, and some of them have been crystallized. There is evidence that the viruses are substances able to induce in the host cells the capacity to produce further quantities of the same substance. The virus particles are equivalent in size to very large protein molecules.

Viruses are usually systemic in the host plant, consequently vegetative methods of propagation will ensure the continuation of the disease in new stocks. For example, tubers, corms, bulbs, rhizomes and " cuttings " from infected plants will give rise to more infected plants. Grafting or " budding " of infected material on to healthy plants will also lead to infection.

Apart from perpetuating viruses by vegetative propagation and producing infection through grafting and " budding," there are other means by which viruses may be spread in nature. Some viruses are sap-transmissible and can be inoculated into healthy plants by rubbing the leaves with infected sap. To this group belong many of the Mosaic diseases, including tobacco Mosaic (caused by the same virus as tomato Mosaic), first shown to be sap-transmissible by Ivanowsky in 1892. Most viruses, however, including many of those affecting potatoes, are transmitted by sucking insects belonging mainly to the Order known as the *Hemiptera*. Chief among these carriers or vectors are the greenfly (*Aphididae*) and leaf-hoppers (*Jassidae*). Thrips, although not in the group *Hemiptera*, is also of importance as an insect vector. Successful control measures depend upon an intimate knowledge of the means of transmission and can best be illustrated by considering the virus diseases of a few common farm crops.

POTATO. There are many virus diseases of potato, the symptoms depending upon the particular virus or combination of viruses present in the plant. The potato viruses of greatest economic importance in this country are those that cause Leaf Roll and Rugose Mosaic. A common symptom of the first-year or primary infection with Rugose Mosaic virus is Leaf Drop Streak. Mottle (Mild Mosaic) and Crinkle are also very common but do not cause so much concern. There are other virus diseases such as Tuber Blotch, Net Necrosis and Aucuba Mosaic, but these are relatively unimportant.

Leaf Roll. Infected tubers are normal in appearance and give rise to normal shoots, and there are no simple means of distinguishing infected from healthy tubers. The development of plants from infected tubers is usually slightly retarded and the subsequent foliage rather pale in colour. A few weeks after the shoots have appeared above ground the lower leaves commence rolling upwards around the mid-ribs, an effect which is more pronounced at the base of the leaflets than at the tips. The rolled leaves are thicker, harder and more brittle than healthy leaves, and the plants rattle when shaken. Symptoms arising in plants growing from previously infected tubers are referred to as Secondary Leaf Roll. Varieties vary greatly in the extent to which the foliage may show Leaf Roll, and although some plants may be stunted in growth this is not invariably so, even in the same variety. The extent to which tuber yield is affected by Leaf Roll may be considerable.

Great Scot and Up-to-Date generally give only slight signs of Leaf Roll, only one or two of the lowest leaves showing symptoms. Arran Comrade may show only the lower third of the leaves affected, while the variety Craig's Defiance and the now little-grown variety President are highly susceptible.

For the purpose of diagnosis the character of the lower leaves must always be observed, for it is in these that the symptoms are most apparent.

Plants severely affected with Leaf Roll produce only a small crop of tubers that are generally few in number and small. The " mother " tuber often remains to the end of the season hard and unrotted in the soil, although this failure to decompose may arise from other causes. Plants that become

infected during the season show symptoms only if infection occurred very early. Following early infections, rolling of the leaflets of the upper leaves may take place later in the season, and the younger foliage assume a more pallid green with a "staring" habit characteristic of the stage referred to as Primary Leaf Roll. Tubers that are infected through the chits before planting show typical Secondary Leaf Roll symptoms. Leaf Roll virus can be transmitted from infected to healthy plants by grafting, but in nature it is spread mainly by *Aphides* or greenfly. The most important of these is *Myzus persicae*, which thrives in the warmer, drier parts of the country, and it is in these localities that degeneration of potato stocks takes place most rapidly. Transmission cannot be effected by contact between the foliage or by artificially inoculating healthy plants with sap from infected plants.

Leaf Roll is found in most potato-growing areas, but some of the best seed-growing districts in cool, moist, exposed uplands are relatively free from the disease. In these surroundings it is possible, by carefully roguing all affected plants, to maintain stocks of potatoes almost completely free from Leaf Roll and also Rugose Mosaic, a disease that is transmitted in the same way. The risk of spreading virus in these crops is also reduced by the premature destruction of the haulm towards the end of the season before the aphis population becomes numerous. From these areas it is possible to supply seed potatoes almost free from virus for the ware-growing districts where heavy yields may be grown. In the latter districts, however, the stocks are again subject to rapid degeneration if seed is saved for replanting in subsequent years.

Degeneration is rapid in the ware-growing areas and depends on the intensity of the population of the aphides which spread the disease, and the prevalence of infected plants from which the virus can be spread. The aphis is a sucking insect equipped with a needle-like feeding organ called a proboscis, and with this it pierces the host tissues and sucks the cell sap. In the act of penetrating the host it injects the plant with a small quantity of the sap drawn from the previous plant upon which it fed. In this way aphides flying from degenerate to healthy crops rapidly infect a large number of plants that subsequently produce tubers containing the virus. It is for this reason that seed tubers

from such crops give rise the following year to a high proportion of virus-infected plants. Each year the virus is spread and the number of infected plants increases until the stock is completely degenerate. The practice of selecting small tubers for seed also increases the proportion of diseased plants in the subsequent crop owing to the tendency of such plants to produce seed-sized tubers. Although tubers infected with Leaf-Roll virus are usually indistinguishable from those that are virus-free, some varieties, e.g., Golden Wonder and Catriona, occasionally show a characteristic necrosis of the vascular tissue towards the heel-end associated with first year or primary infection ; these symptoms are referred to as Net Necrosis.

Mosaic. Another serious virus disease of the potato is Rugose Mosaic, sometimes called Leaf Drop Streak because of the characteristic symptoms attending primary infection. This virus is also carried by aphides in the same way as Leaf Roll. Primary infection produces striking symptoms in most varieties. Shortly after infection occurs, dark streaks develop on the veins on the lower sides of the leaves, and these extend down the petioles to the main stem. Necrosis gradually involves the whole leaf, which is killed and hangs down, but remains attached to the stem by a thin thread of tissue. Leaves are progressively affected from the base of the plant upwards. The top foliage remains green, but is mottled. The haulm ultimately bears only the topmost leaves in a green condition, with the lower leaves dead and hanging downwards attached to the stem. All varieties are not equally affected, and a few, while carrying the virus, show no symptoms, e.g., Di Vernon. Symptoms are usually marked in Majestic but barely noticeable in Arran Pilot. No symptoms in the tuber have been described for any variety. Secondary infection does not show the leaf drop that is so characteristic of primary infection. Infected tubers of susceptible varieties give rise to plants that are stunted and bear pale-green leaves that are crinkled and show distinct mottling, in contrast to the undistorted, dark-green leaves of normal plants. It is from these features that the name Rugose Mosaic has arisen. The stems later become weak and prostrate and very few tubers are produced.

Mottle and Crinkle. Mottle (Mild Mosaic) is one of the most widespread of the virus diseases, and stocks of many varieties are almost wholly affected. The growth of infected plants of most varieties, however, is normal, with no apparent loss in vigour. The principal symptom is a more or less distinct mottling or mosaic of the leaves with light and dark-green patches. The intensity of mosaic varies with different varieties; it is very obvious in some and barely perceptible in others. It may be so slight that only when the leaves are held up to the light, or over a sheet of white paper, can the faint mottling be observed. Although apparently unaffected themselves, varieties showing negligible symptoms remain a source of infection, for the virus can be transmitted to other varieties that may be severely affected and in which some reduction of yield may occur. Mottle results from single infection with one or other of several distinct viruses. Two of these (X and A), when present together in some varieties, produce the symptoms known as Crinkle. Affected plants are dwarfed and bushy and there is a marked downward curling and puckering of the leaves, and the foliage is paler green than in healthy plants. The potato virus X differs from the viruses causing Leaf Roll and Rugose Mosaic, in that it is not carried by insects but by contact between diseased and healthy haulm. Aucuba Mosaic, in which rather bright yellow spots are scattered over the leaf surface, is one of several other virus diseases, but of a very mild type ; so far as is known, loss in yield is negligible.

Control of Potato Virus Diseases. For many years virus-free seed has been produced in suitable districts in Scotland and Ireland, and more recently in parts of England and Wales, for planting in the ware-growing districts. In localities where aphides are abundant many growers find it very profitable to use fresh seed stocks each year, but in other areas the progeny can be carried over into the second and sometimes the third year before fresh seed is necessary. To enable purchasers to be sure of the quality of seed, the Departments of Agriculture established a voluntary scheme of certification and growers are well-advised to purchase only certified seed. The following classes of health certificate are issued under the certification scheme :

"S.S." (STOCK SEED) CERTIFICATE for seed from crops 99.95 per cent. true to type, that contain not more than 0.25 per cent. of virus diseases and wildings, including not more than 4 plants per acre affected with severe virus diseases and wildings.

Stock Seed is the highest grade of seed, specially suitable for the production of seed potatoes in recognised seed-growing areas.

"A" CERTIFICATE for seed from crops 99.5 per cent. true to type and which contain not more than 1 per cent. of readily visible virus diseases and wildings, of which not more than 0.5 per cent. may be Leaf Roll, Rugose Mosaic and wildings.

Seed with an "A" certificate may be regarded as the best grade of seed for commercial ware production.

"H" CERTIFICATE for seed from crops 99.5 per cent. true to type and which contain not more than 3 per cent. of the diseases Leaf Roll and Rugose Mosaic, and of wildings.

It is probable that the period of health of a potato stock may be prolonged by isolating it from Brassica crops, for it is here (and upon peaches) that *Myzus persicae*, the chief vector of virus diseases, mainly hibernates. Potato crops grown for seed production should certainly not be grown adjacent to cabbages and related plants. On certain other crops, measures are taken to destroy the aphis by fumigation with nicotine vapour. This method, however, is not used for potatoes.

SUGAR BEET. In recent years virus diseases of sugar beet have become increasingly important and are now causing grave concern to the beet-sugar industry, especially in the Eastern Counties of England, where the crop is of great importance. The diseases concerned are Mosaic and Virus Yellows, both of which are spread by aphides, but it is Virus Yellows that causes the greater loss.

Mosaic. This disease was first recorded in Germany in 1926, but a condition of beet described in 1898 in France and called "jaunisse" or jaundice is believed to have been the same disease. It is now prevalent in most of Europe and the United States of America. Primary symptoms are the "clearing" or yellowing of the veins of the young heart leaves, followed by the development of a pale-green or yellow mottling, and the leaves may become puckered and distorted. This curling is often followed by the death of the tips of the leaves. Severely-affected plants are checked, dwarfed and deformed, and the sugar content and yield are reduced.

Virus Yellows. The symptoms of Virus Yellows differ from Mosaic in that it is the older and outer leaves that show the most marked symptoms. When first affected the leaves develop a fine network effect and the pallor between the veins becomes more pronounced until they are uniformly yellow. The outer yellowed leaves are thick and brittle, and crackle when brushed against or crushed in the hands. The central leaves generally remain green. The leaves of a severely-affected beet crop subsequently have a scorched appearance and the plants may be defoliated. Scorching most frequently starts at the tips or margins and gradually involves the whole leaf area. Various saprophytic fungi may then develop on the dead or dying tissues. With later infections, from the end of August onwards, typical yellowing results, but this is not always followed by necrosis. When crops are severely affected *early* in the season a loss in potential yield of sugar may be as much as 50 per cent.

Control of Beet Mosaic and Virus Yellows. There is no evidence that these viruses are carried by the seed, but two species of aphides are known to carry infection, *Myzus persicae* and *Aphis fabae*. Mild winters favour the over-wintering of aphides, and the early spread of beet viruses is most marked in seasons when the vectors are most prevalent. Severe and early infection of root crops can occur if they become infested with aphides migrating from nearby sources of infection. Common sources from which the disease may spread to root crops are sugar-beet and mangold seed crops, overwintering beet tops and other susceptible crops such as seakale beet and winter spinach. The most probable sources, however, are sugar-beet and mangold seed crops, infection having been transmitted to the stecklings the previous autumn from neighbouring root crops.

It is most important, therefore, to raise seed crops as free as possible from virus, and this is best done by planting, in the first place, only disease-free stecklings. This would be possible by raising them in areas relatively free from aphides or where the sources of infection are few. When this is not practicable, the steckling beds must be kept as far as possible from root and seed crops and from autumn sources of aphides. In seasons when virus infection is severe and prevalent it is

best also to sow late so that the seedlings emerge after the main summer migration of aphides is over. Root crops, however, are best sown as early as possible and they should be kept well separated from seed crops. At present, none of the commercial varieties in general cultivation is resistant.

CABBAGE AND RELATED CROPS. Several viruses attack cabbage and related crops, but only two are important; one that attacks broccoli and cauliflower, and the other a wide range of cruciferous crops. Both viruses are aphis-transmitted, especially by the mealy cabbage aphis *Brevicoryne brassicae* and by *Myzus persicae*.

The Cauliflower Mosaic virus causes stunting, curling and distortion of the leaves. The heads usually develop poorly or fail to set. Later, the leaves may develop irregularly-shaped patches of dark green, giving a mottled effect.

The second virus, known as the Black Ring Spot virus, is much more serious in its effect, and causes necrotic spotting of the foliage, accompanied by curling and dwarfing. Soft rot and other organisms later invade the dead tissues and the plants frequently become completely rotten ; broccoli are most susceptible. This virus is probably most familiar as the cause of the attractive " broken " colours induced in self-coloured wallflowers and stocks.

No satisfactory control is at present known, but the different varieties of cruciferous crops show great variation in their reaction to virus infection, and it may be that resistant strains will be developed in the future.

LEGUMES. There are many viruses that produce various forms of Mosaic in leguminous crops, including beans, peas, clovers, lucerne and lupins, and the majority are aphis-transmitted. One of the most common is the virus causing the common Mosaic of field bean. This virus also causes Mosaic in peas, and, in varieties with coloured flowers and in sweet peas, causes " flower break."

TOMATO. Among the commonest diseases of tomatoes are several caused by viruses, and one of them, Mosaic in its mild form, is so common that it fails to attract the attention of

many growers. Symptoms vary considerably, however, and plants may suffer severely with resultant loss in yield.

Mosaic. Pale-green or yellowish mottling of the foliage marks the mild form of this disease, but the symptoms vary with the season. In winter the mottling may be accompanied by distortion, and even reduction of the blade of the leaves to give a fern-like effect. Towards the end of the season parts of the affected leaves may also become dry and necrotic. When infection takes place after the plants are well-grown, however, it is usually only the younger leaves that develop the typical mottle and the older leaves remain normal in appearance. Affected plants are often less vigorous and sometimes the fruit ripens irregularly and is blotchy in appearance. The disease becomes serious only in plants that are poorly nourished and making little growth, and much can be done by feeding to counteract the general effect of the virus on growth. Aucuba Mosaic is a more severe form and the principal symptom is a very pronounced bright-yellow mottle of the foliage, and frequently of the fruit.

The Mosaic virus is highly infectious and is transmitted from plant to plant in traces of sap carried on the fingers of workers or on pruning knives. Transmission by insects does not take place, but soil infection may occur through injured roots coming into contact with infected plant remains in the soil. The virus is very resistant to drying and is known to remain viable in dead plant tissue for many decades. Among the susceptible hosts is the tobacco plant, and outbreaks can frequently be traced to cigarettes and pipe tobacco, for the virus can survive the curing process and be transmitted on the hands of workers.

Sterilization of the soil with steam or formaldehyde helps to remove the risk of infection from débris in the soil, and any possible chance of transmission by the seed may be avoided by saving fruit only from disease-free plants. When the disease is present in a growing crop, control measures greatly depend upon the number and the size of the plants affected. When these are few in number, and before they have grown sufficiently to infect neighbouring plants by leaf contact, they may be removed and burnt. At a later stage, however, the adjacent plants will already have become infected and roguing is of little

avail. Pruning and handling of infected plants should, if possible, be left till last ; afterwards the knives and hands should be washed thoroughly with soap and water. Avoidance of smoking while handling tomato plants, especially at pricking-out time, is also a wise precaution.

Streak. This disease is due to a more virulent virus closely related to the one causing Mosaic or, less commonly, to a mixture of the tomato Mosaic virus and potato virus X. The leaves are mottled and distorted, often with brown necrotic markings. Dark-brown, longitudinal streaks or stripes appear on the stems and leaf stalks, and the fruit may show rounded, irregular, brown blotches, and brown, sunken pits. In mixed virus Streak, however, the fruit markings are raised brown spots. Occasionally, in the absence of stripe markings, a mottle resembling Mosaic is produced.

Transmission is the same as that for Mosaic and the control measures are similar. Attacks may be severe in plants manured with an excess of nitrogenous fertilizers, or if the plants are in a poorly-nourished condition. Dressings of potash help to counteract the disease by promoting more balanced growth.

Spotted Wilt. In Britain the disease was first recognised in 1931, and it is now widely distributed, especially under glass. Young leaves are the first to show typical symptoms and become bronzed with irregular or rounded, ringlike, brown markings. Leaves on further new growth also develop symptoms and may become distorted. Infected plants are checked and, although they may not die, remain in a dwarfed condition. The upper leaves curve downwards and inwards in a manner suggestive of wilting. Bronze markings or yellowish blotches appear on the fruit and considerably reduce the market value. Spotted Wilt affects a wide range of hosts, including many ornamentals and some weeds. Over 100 possible hosts are now known and many belong to the tomato and potato family (*Solanaceae*). The disease is most prevalent in mixed nurseries where tomato plants and ornamentals are grown in close proximity.

There is no cure for Spotted Wilt, but its spread can be reduced if the insect vector, a species of thrips, is controlled by fumigation or spraying. All infected plants should be

removed and destroyed. The tomato crop, moreover, should not be grown in the same houses as other susceptible hosts. Weeds, such as the nightshades, that are capable of carrying the virus, should be suppressed in the vicinity of the crop.

FERN LEAF. This is a fairly common disease of outdoor tomatoes caused by infection with the Cucumber Mosaic virus. The symptoms may be confused occasionally with those caused by one of the more virulent strains of Tobacco Mosaic. The virus is transmitted by aphides and is not spread by handling. Other plants such as cucumbers, marrows, dahlias, etc., are also susceptible.

OTHER CROPS. Many crops are affected by viruses, and these are described in standard works on the subject.* Examples of virus diseases of other common crops are Lettuce Mosaic, Strawberry Yellow Edge, Strawberry Crinkle and Raspberry Leaf Curl.

*Smith, K. M. *A Textbook of Plant Virus Diseases.* Churchill, 1937.
Bawden, F. C. *Plant Viruses and Virus Diseases,* 2nd ed. Chronica Botanica Co., Waltham, Mass., and Wm. Dawson, London, 1943, 294 pp.

1 2

1. Speckled Yellows of sugar beet. 2. Early stages in Heart and Dry Rot of sugar beet.

PLATE LVIII

(By permission of the Ministry of Agriculture and Fisheries)

(By permission of the Ministry of Agriculture and Fisheries)

Examining seed samples in the Official Seed Testing Station, Cambridge.

PLATE LIX

Map of England and Wales showing the eight Advisory Provinces and the approximate positions of the Advisory Centres.

PLATE LX

(By permission of the Ministry of Agriculture and Fisheries)

The National Institute of Agricultural Botany, Huntingdon Road, Cambridge.

Chapter Seventeen

Legislation

Many are the ways in which disease may be spread, but man himself is one of the prime agencies in its transference, and many highly undesirable parasitic immigrants have found their way with his aid to countries previously free from them. Hunger for travel and adventure, and interest in the rare and unusual, have always stirred in man's heart, and the same urge has blazed the trail of international commerce through the centuries. Improvements in travel, speed of passage from one country to another, and the ever-increasing volume of international trade, have all combined to make easy the accidental transference of pests and diseases to new countries.

Not all such migrations have been accidental, however, for the collector's instinct and man's interest in the unusual have also played their part. In this way the rabbit gained entry into Australia in 1788 as a pet, and, free from natural enemies, became so numerous as to be a serious menace. In Australia also the prickly pear (*Opuntia vulgaris*) became rampant, and a deadly enemy, after having been imported as a desirable garden plant. Canadian water weed (*Elodea Canadensis*), which at one time threatened to block the waterways of many English rivers, originated from N. America and was first observed between 1842 and 1847 in Cambridge and near Market Harborough.

Not all importations of plants and animals are dangerous, of course, but even the most innocent consignments may have lurking in them some new and potentially troublesome pest or disease. This was so in 1865 when rinderpest (cattle plague) broke out in Britain following the importation of some Russian cattle carrying the disease. Only prompt destruction of all affected cattle, through emergency powers given to the Government by Act of Parliament in 1866, enabled the problem to be dealt with, and by the end of the following year the disease had been suppressed. As a precautionary measure,

to prevent a recurrence, the Contagious Diseases (Animals) Act was passed in 1869 to regulate the import of cattle from countries in which the disease was common. It was not until 1883, however, that an Agricultural Department (of the Privy Council) was created, and was later to be responsible for, among other things, the administering of such legislation as related to agriculture, including the control of crop pests and diseases. That Department developed into first the Board of Agriculture in 1889, and then the Ministry of Agriculture and Fisheries in 1919.

Early in the nineteenth century a small, yellowish-winged beetle with five black lines on each wing case, the Colorado Beetle (*Leptinotarsa decemlineata*), had been observed in Colorado feeding on wild plants related to the potato. It was this beetle that was ultimately to stimulate the extension of legislation for crop protection in Britain. Until the cultivation of potatoes extended westward to the Rockies the beetle did little harm, but by the eighteen-sixties it had become a voracious feeder on the potato plant and had begun its eastward spread. By 1873 it had reached the Atlantic seaboard of the United States and Canada. Interest in this now notorious pest was aroused in Britain, but interest turned to alarm in 1877 when it was found in Germany. In that year a law was enacted to restrain the importation of live beetles by collectors, and to give powers to inspect imported agricultural produce at the ports of entry. Powers were also given to impose, if necessary, restriction or prohibition on such imports. This law, the Destructive Insects and Pests Act 1877, was amended in 1907 to cover all insect pests. In 1927 it was further amended to define the meaning of "crop" and "insect," and to include within the meaning of the Act "bacteria and other vegetable or animal organisms, and any agent causative of a transmissible crop disease." The expression "crop" included "seed, plant, or any part thereof." The necessary powers were thus given to the Ministry of Agriculture for effective measures to be taken against such diseases as may be "scheduled" as being dangerous. The following is the text of the enactment of 1927 :

Destructive Insects and Pests Act, 1927

An Act to amend the Destructive Insects and Pests Acts, 1877 and 1907. (22nd December, 1927).

Be it enacted by the King's most Excellent Majesty, by and with the advice and consent of the Lords Spiritual and Temporal, and Commons, in this present Parliament assembled, and by the authority of the same, as follows :—

1.—(1) An Order under the Destructive Insects Act, 1877, as amended by the Destructive Insects and Pests Act, 1907 (which Act as so amended is hereinafter referred to as the principal Act), may—

(*a*) enable any inspector authorised by the Minister of Agriculture and Fisheries to remove or destroy, or cause to be removed or destroyed, any crop infected with an insect which has been introduced into Great Britain specified in the order, being a destructive insect within the meaning of the principal Act, or any crop to or by means of which the insect is likely to spread, and generally to take such steps as he may think expedient in connection with any crop for preventing the spreading of any such destructive insect, and to enter on any lands for any of the purposes aforesaid, or for any examination or inquiry authorised by the order, or any other purpose of the order ;

(*b*) impose in respect of any certificate given in pursuance of the order after an inspection such fee or other charge as, with the consent of the Treasury, may be prescribed by the Minister ;

(*c*) impose as a maximum penalty in respect of a second or subsequent offence against the order a fine of fifty pounds.

(2) The Minister may out of moneys provided by Parliament pay compensation (to be ascertained in accordance with the provisions of the principal Act) in respect of any crop removed or destroyed by or under the instructions of an inspector authorised by him, and any other expenses incurred by him in the execution of the principal Act :

Provided that the amount of the compensation and expenses so paid shall not in any one year, without the consent of the Treasury, exceed the sum of two thousand pounds.

(3) Notwithstanding anything in the Summary Jurisdiction Acts, proceedings for an offence against an order under the principal Act may, where the offence is an offence in connection with the movement, sale, consignment or planting of potatoes, be instituted at any time within twelve months from the day on which the alleged offence was committed.

(4) Paragraphs (1) and (2) of section three of the principal Act, and in paragraph (3) thereof the words " in ordinary circumstances," are hereby repealed.

(5) For the purposes of the principal Act, the expression " insect " shall include bacteria and other vegetable or animal organisms, and any agent causative of a transmissible crop disease ; and the expression " crop " shall include seed, plant, or any part thereof.

2.—(1) This Act may be cited as the Destructive Insects and Pests Act, 1927, and shall be construed as one with the principal Act, and the Destructive Insects and Pests Acts, 1877 and 1907, and this Act

may be cited together as the Destructive Insects and Pests Acts, 1877 to 1927.

(2) In the application of this Act to Scotland the Board of Agriculture for Scotland shall be substituted for the Minister of Agriculture and Fisheries.

(3) This Act shall not extend to Northern Ireland.

Besides Colorado Beetle, many other parasites have made spectacular migrations, and the origins of many are known with considerable certainty. For example, in America, the now serious disease Chestnut Blight (*Endothia parasitica*) was first noted in 1904 in New York Zoological Park, having come from China; and in 1915 the White Pine Blister Rust (*Cronartium ribicola*) arrived from Europe. Dutch Elm Disease (*Ceratostomella Ulmi*), first described in Holland at Tilburgh in North Brabant in September, 1919, spread rapidly over the greater part of Western Europe and Scandinavia. It was first observed in England at Totteridge, near London, in July, 1927, but it is probable that it was already present the previous year, for a number of elms were reported as having died nearby. In 1928 a survey was made and the disease was found in 19 counties. By 1930 it had reached the U.S.A.

To combat the distribution of diseases, laws for the imposition of plant quarantines now exist in almost all countries. In Britain the first Orders made under the Destructive Insects and Pests Acts, 1877-1907, were directed against Wart Disease of potato (*Synchytrium endobioticum*) and American Gooseberry Mildew (*Sphaerotheca mors-uvae*). Wart Disease had been described in mid-Europe in 1898 and the first records in Britain were made two years later. The first accurate description of the disease in this country, however, was published in 1902 and related to material collected in Cheshire in 1900. The disease was "scheduled" in 1908 and made notifiable, since when various Orders have been issued, the latest being in 1941. By 1909 the disease had crossed the Atlantic to Newfoundland, and by 1918 it had reached the U.S.A.

American Gooseberry Mildew, on the other hand, was known to be present in the U.S.A. more than 50 years before it was observed in Europe, and undoubtedly it came to Britain from America. The disease was introduced into Southern Russia in 1890 on imported bushes, and by similar means it became established in a garden in north-east Ireland in 1900,

and by 1906 was in England near Evesham. Since then the disease has spread over the whole of Europe. At first it was rampant, but later its intensity diminished and in Britain the Order was relaxed. Growers were no longer required to notify the presence of American Gooseberry Mildew in their gardens or plantations, but under the Sale of Diseased Plants Orders of 1927 to 1943 the sale of any bushes that are substantially affected with the disease is still prohibited.

In time more diseases were scheduled, and various Orders were issued under the Act. At first these were directed primarily against the importation of specific diseases and pests, but an Order made in 1933 replaced the schedule with general regulations covering a wide range of pests and diseases. The Act also conferred powers for measures to be taken against those already present in the country. The work of legislation thus tends to be directed into two distinct channels : the exclusion of all potentially dangerous pests and diseases not yet established in this country, and the control, or limitation of spread, of those that are already resident, or have gained entry despite precautions to exclude them. For the provision of technical guidance and advice in the administration of the various Orders, the Ministry of Agriculture and Fisheries established a Plant Pathology Laboratory, now situated at Harpenden, Hertfordshire. An interesting development in the application of internal legislation is the power conferred upon the Ministry of Agriculture by the Sugar-Beet Eelworm Order, 1943, to prohibit, in certain scheduled areas, rotations that would encourage the increase and spread of beet eelworm. This aspect of disease control is of the greatest importance.

From an international aspect the control of pests and diseases by plant quarantine regulations, although justified by sound scientific fact, involves many economic and political difficulties. A considerable measure of international co-operation is necessary to avoid undue interference with the normal flow of trade and to minimise national resentment. Smooth-working international regulations must also permit the introduction of new varieties and new crop plants, for this is essential for the economic development of agriculture in all countries. Impediments to international exchange are detrimental to agricultural science. The convention that met in

1881, to deal with the disastrous *Phylloxera* epidemic on vines which raged throughout Europe at the time, was one of the earliest attempts at international co-operation. The first International Phytopathological Conference met in Rome in May, 1914.

It is clear that the casual introduction of plant material from other countries is potentially dangerous. The importance of this cannot be over-emphasised, especially in modern conditions of air transport, when so many travellers are moving to and from all parts of the world. New introductions of even the commonplace diseases may cause serious loss by establishing new physiologic races that may result in the breakdown in resistance of varieties previously immune. Quarantine regulations should never be disregarded.

The earliest known legal measures against plant disease were internal local controls, and were those enacted in France in 1660 at Rouen and in Massachusetts in 1755, for the eradication of the common barberry (*Berberis vulgaris*). The purpose of this was not clearly understood at the time, but the people quite rightly inferred that a connection existed between this shrub and severe outbreaks of Black Rust of wheat (*Puccinia graminis*). A similar opinion was held in Britain, but here the eradication of barberry proceeded on a voluntary basis unaided by Public Acts. There have been a number of examples since then of voluntary schemes, notably for the granting of certificates of health for certain crops ; one of the earliest concerned the certification of blackcurrants for trueness to type and apparent freedom from the virus causing Reversion.* The potato certification scheme, although originating under the Wart Disease Order, was later extended on a voluntary basis to include the virus diseases.

This voluntary approach in dealing with a major problem was again evident in 1943, when the Ministry of Agriculture promoted a scheme for the official approval of proprietary products for the control of plant pests and diseases.† The scheme is designed to satisfy two essentials : (1) " that persons professionally concerned with giving advice on the control of

*The Sale of Strawberry Plants and Blackcurrant Bushes Order 1946 now prohibits the sale in England and Wales of strawberry plants and blackcurrant bushes unless they are from stocks that have been certified.

†*Agriculture*, 1943, **50**, 331.

plant pests and diseases should be able, on reasonably sure foundations, to recommend by name an appropriate range of products ; and (2) that the consumer should be able to see at a glance that the product he is purchasing is a good one for his purpose."

For the guidance of the adviser, classified lists of the approved products are published periodically. For the information of adviser and grower, each package of an approved product bears the brand name and the official diamond-shaped approval mark. The products are classified into two sections, both containing a number of groups arranged according to their purpose and composition. The first section includes products guaranteed by their makers to conform to an official specification. The second section comprises those for which no official specification is at the time available, but for which the chief active ingredients are declared, or are not considered as secret by the makers. These products must fulfil certain conditions before approval can be given, and even when this has been granted it may be withdrawn later if the undertakings originally given are broken. It is clear, of course, that the intrinsic test of any fungicide or insecticide is the control that it gives in the field, and this matter is carefully considered before approval is granted, but official trials are not conducted to test their efficacy. The present scheme, although not perfect, does much to eliminate many undesirable and ineffective " quack " recipes from the market, and gives the farmer added confidence in his choice of products. The scheme is entirely voluntary, and participation is open to " any manufacturer in Great Britain and to those manufacturers abroad who have responsible selling agents resident in Great Britain."

Although the cultivation of a crop is satisfactory, and precautions have been taken to prevent the depredations of pests and diseases, the best yield may not be obtained unless good seed has been planted. The need for ensuring good seed is so important that, in August, 1920, an Act was added to the Statute Book " to amend the Law with respect to the Sale and Use of Seeds for sowing and of Seed Potatoes and to provide for the testing thereof." The Act, officially cited as the Seeds Act, 1920, provided for declarations to be made by the

seller as to the variety, purity and percentage germination of all seed offered for sale for sowing. For potatoes, a declaration must be made of the class of seed, variety, size and dressing.

Provision was also made for the prohibition of the sale or the sowing of seeds containing more than a prescribed percentage of certain injurious weed seeds (see Ch. 3). To comply with the Act tests must be made at one of the official stations or at some other centre licensed by the Minister of Agriculture. Under the Act, Official Seed Testing Stations were established at Cambridge for England and Wales ; at Corstorphine, Edinburgh, for Scotland ; and at Queen's University, Belfast, to serve Northern Ireland.

Chapter Eighteen

Technical Advice

The first step towards the provision of technical advice to farmers took place in 1889, with the passage of the Technical Instruction Act, by which the local authorities were empowered to provide technical instruction, including instruction in agriculture. This was facilitated by the provision of a special grant in 1890, and by 1908 eight counties had appointed Agricultural Organisers responsible for giving advice in technical matters and supervising agricultural education. By 1939 most counties, either individually or sharing with another county, employed full-time Agricultural Organisers. On the staff of County Organisers were various specialists dealing with such subjects as horticulture, dairying, poultry and bee-keeping.

The employment and payment of these organisers depended solely upon the county concerned, but the Ministry of Agriculture (formerly the Board of Agriculture) assisted in their maintenance by means of grants for agricultural education. Although not empowered by statute to provide and maintain educational and advisory services, the Ministry of Agriculture could foster these services by giving financial aid. In the same way the Ministry was enabled to sponsor the development of Provincial Advisory Centres, which were to be established and maintained by universities and agricultural colleges. It was thus that the Provincial Advisory Service was inaugurated, following the recommendation of the Development Commissioners in 1911 that annual grants should be paid to certain universities and agricultural colleges in England and Wales, to assist them in supplying technical advice. This organisation continued until October 1st, 1946, when it was superseded by the National Agricultural Advisory Service, or N.A.A.S., under the general guidance of the Agricultural Improvement Council.

How may advice on agricultural problems now be sought ?

For every district of about one thousand farms there is a District Advisory Officer whose responsibility it is to advise the farmer and keep him informed of the latest developments in agriculture. The farmer, therefore, should seek advice from his District Advisory Officer, who will deal with the problem and, if necessary, obtain specialised information from county or provincial centres.

The work in each county is administered by a County Advisory Officer, and attached to his staff are specialists in different branches of agriculture and horticulture. There are occasions, however, when the advice required is upon a subject that entails a high degree of specialisation ; for this purpose, and for the general administration of the service, the counties are grouped together into Provinces, each of which is administered by a Provincial Director. There are eight Provinces in England and Wales, and the headquarters of each is situated near an agricultural college or a university with a department of agriculture. The Provincial Advisory Centres are :

Province	*Centre*
Northern	Elswick Hall, Newcastle upon Tyne
Yorks. and Lancs.	Weetwood Lane, Leeds
West Midland	Tettenhall, near Wolverhampton
East Midland	Shardlow Hall, near Derby
South-West	Bristol (sub-centre at Starcross, near Exeter)
South-East	Caversham, Reading (sub-centre at Wye, Kent)
Eastern	Trumpington, Cambridge
Wales	Crosswood, Aberystwyth (sub-centres at Bangor and Cardiff)

At each Provincial Advisory Centre there is a team of specialists dealing with plant pathology, entomology, bacteriology, chemistry, animal nutrition, etc., and they deal with specific inquiries in these subjects received from the county staffs in their Province. The specialist staff also maintains close contact with new advances and research in agriculture, and often it is as a result of inquiries received that new research is initiated into practical agricultural problems. For dealing with special problems in various classes of crops, there are several research centres with which the work of the service is co-ordinated, and all new developments are watched by the adviser who is ready to apply, in practical advice, the knowledge so gained. At a later date it is likely that a chain of

Husbandry Experimental Farms and Horticultural Stations will also be linked up with the Advisory Centres.

The staffs of the Advisory Service constitute a team that, working in close collaboration with farmers and growers, can bring a wealth of knowledge and practical experience to bear upon agricultural problems so that they may be dealt with in a realistic way. " It is the inevitable consequence of the increase of scientific knowledge about food production that the all-round man, whether he be an agriculturist or a horticulturist, can no longer profess to know the answers to all the questions that he may fairly be asked. The general advisers must, indeed, still constitute the front line of the service. It is only they who can maintain close personal contact with the individual producer, and it is only they who can have the detailed local knowledge that is essential if science is to be brought to bear on the particular problem. But, like the trusted family physician, the general practitioner in food production increasingly requires the backing, in case of difficulty, of the specialist. Hence under the new scheme there will be, either in the county itself or at the headquarters of the Province, someone who is expert on pastures or potatoes, tomatoes, apples, weed-killers, fertilizers, tractors, calf-rearing, sheep-breeding, or any other subject on which advice may be required."*

In Scotland the Advisory Services are financed by the State through the Department of Agriculture for Scotland, and they are administered by the three agricultural colleges at Aberdeen, Glasgow and Edinburgh respectively. All advice and county extension work is run by the three centres, and there is no separate service run by the county or burgh education committees. The Department of Agriculture for Scotland also maintains a separate Plant Pathology Laboratory near Edinburgh.

Apart from general advice, the farmer may also require other information of a routine character, for example, the germination capacity of his seed samples, provision for which has been made by the establishment of Official Seed Testing Stations. Additional services are also available for examining seed for the presence of organisms causing disease.

*J. A. Scott Watson, *Agriculture*, Jour. Min. Agric., **52**, 469-471.

Many difficult problems are often solved by the joint efforts of both farmer and adviser in the course of an advisory visit, and many of the obscure points may be cleared up in personal discussion. Much general information remains, however, which the farmer may later wish to obtain. There is a great need then, for a handy means of reference to up-to-date knowledge, written in a simple but scientifically accurate form, and strictly practical. These requirements are met by the Advisory Leaflets and Bulletins of the Ministry of Agriculture and Fisheries. The Journal of the Ministry of Agriculture, a monthly periodical, also provides a source of useful information of much value to farmers, and there are, of course, the various trade journals and periodicals. From a plant pathological point of view, a complete collection of the Advisory Leaflets on crop diseases forms a very useful text-book, in which the contents are constantly kept up-to-date.

Disease control and good husbandry are goals towards which every farmer is driving and, in many respects, the means of attaining these ends are the same. Good seed, true to type, and if possible free from disease, should be sown and care taken to choose plant varieties suited to the particular locality and soil type. From seeding time to harvest, correct cultural practices should be adopted, and the crops when safely harvested should be stored properly. Lastly, the marketable products should be graded, and dispatched so as to ensure arrival at their destination in a sound and saleable condition.

Appendix I

Classified List of Diseases

HOST	COMMON NAME	PHYCOMYCETES	ASCOMYCETES	BASIDIOMYCETES	FUNGI IMPERFECTI	OTHER CAUSES OF DISEASE
Apple	Armillaria Root Rot			*Armillaria mellea*		
	Mildew		*Podosphaera leucotricha*			
	Brown Rot and Spur Canker		*Sclerotinia fructigena* (Conidial stage = *Monilia fructigena*)			
	Silver Leaf			*Stereum purpureum*		
	Scab		*Venturia inaequalis* (Conidial stage = *Fusicladium dendriticum*)			
Barley	Ergot		*Claviceps purpurea*			
	Mildew		*Erysiphe graminis*			
	Leaf Stripe		*Pyrenophora graminea* (Conidial stage = *Helminthosporium gramineum*)			

HOST	COMMON NAME	PHYCOMYCETES	ASCOMYCETES	BASIDIOMYCETES	FUNGI IMPERFECTI	OTHER CAUSES OF DISEASE
Barley (cont.)	Net Blotch		*Pyrenophora teres* (Conidial stage = *Helminthosporium teres*)			
	Take-all and Whiteheads		*Ophiobolus graminis*			
	Brown Rust			*Puccinia anomala*		
	Yellow Rust			*Puccinia glumarum*		
	Black Rust			*Puccinia graminis*		
	Covered Smut			*Ustilago Hordei*		
	Loose Smut			*Ustilago nuda*		
Bean, Broad and Field	Chocolate Spot				*Botrytis cinerea* and *B. Fabae*	
	Sclerotinia Disease		*Sclerotinia Trifoliorum* var. *Fabae*			
	Mosaic					Pea mosaic virus
Beet, Sugar and Garden	Leaf Spot				*Cercospora beticola*	
	Violet Root Rot			*Helicobasidium purpureum* (Mycelial stage = *Rhizoctonia Crocorum*)		
	Downy Mildew	*Peronospora Schachtii*				

	Black Leg	*Pythium* spp.	*Corticium Solani* (Mycelial stage = *Rhizoctonia Solani*)		
	Mosaic				Beet mosaic virus
	Yellows				Beet yellows virus
	Heart and Dry Rot				Boron deficiency
	Stringy Root				Nutritional and often associated with acidity
	Speckled Yellows				Manganese deficiency
CABBAGE, CAULIFLOWERS, etc.	Canker			*Phoma lingam*	
	Club Root (Finger and Toe)	*Plasmodiophora Brassicae*			
	Mosaic				Cauliflower mosaic virus
	Black Ringspot				Cabbage ring-spot virus
CARROT	Violet Root Rot		*Helicobasidium purpureum*		
	Soft Rot				*Bacterium carotovorum*
CELERY	Root Rot			*Phoma apiicola*	
	Leaf Spot			*Septoria Apii-graveolentis* & *S. Apii*	

* In this table *Botrytis* spp. are listed under the Fungi Imperfecti as they are conidial forms. Some species of *Botrytis*, however, have been shown to be the imperfect stages of species of *Sclerotinia* and are, therefore, Ascomycetes.

HOST	COMMON NAME	PHYCOMYCETES	ASCOMYCETES	BASIDIOMYCETES	FUNGI IMPERFECTI	OTHER CAUSES OF DISEASE
Celery (cont.)	Soft Rot					*Bacterium carotovorum*
Cherry	Armillaria Root Rot			*Armillaria mellea*		
	Brown Rot		*Sclerotinia fructigena*; *S. laxa* (Conidial stage = *M. cinerea*)			
	Blossom Wilt		*S. laxa*			
	Silver Leaf			*Stereum purpureum*		
Chestnut (*Castanea*)	Blight		*Endothia parasitica*			
Clover	Mildew		*Erysiphe Polygoni*			
	Violet Root Rot			*Helicobasidium purpureum*		
	Rot		*Sclerotinia Trifoliorum*			
Cucumber	Grey Mould				*Botrytis cinerea*	
	Fusarium Wilt				*Fusarium* spp.	
	Verticillium Wilt				*Verticillium albo-atrum*	
	Soft Rot					*Bacterium carotovorum*

	Mosaic				Cucumber mosaic virus
Currant, Black and Red	Armillaria Root Rot		*Armillaria mellea*		
Elm	Dutch Elm Disease	*Ceratostomella Ulmi*			
Gooseberry	Armillaria Root Rot		*Armillaria mellea*		
	American Mildew	*Sphaerotheca mors-uvae*			
Grasses	Ergot	*Claviceps purpurea*			
	Mildew	*Erysiphe graminis*			
	Take-all and Whiteheads	*Ophiobolus graminis*			
Hop	Mildew (Red Mould)	*Sphaerotheca Humuli*			
Lettuce	Grey Mould			*Botrytis cinerea*	
	Mosaic				Lettuce mosaic virus
Lucerne	Violet Root Rot		*Helicobasidium purpureum*		
	Rot	*Sclerotinia Trifoliorum*			
Oak (and other forest trees)	Armillaria Root Rot		*Armillaria mellea*		
Oats	Mildew	*Erysiphe graminis*			
	Crown Rust		*Puccinia coronata*		
	Black Rust		*Puccinia graminis*		

HOST	COMMON NAME	PHYCOMYCETES	ASCOMYCETES	BASIDIOMYCETES	FUNGI IMPERFECTI	OTHER CAUSES OF DISEASE
Oats (cont.)	Leaf Spot and Seedling Blight		*Pyrenophora Avenae* (Conidial stage = *Helminthosporium Avenae*)			
	Loose Smut			*Ustilago Avenae*		
	Covered Smut			*Ustilago Kolleri*		
	Grey Leaf					Manganese deficiency
Onion	Downy Mildew	*Peronospora destructor*				
Pea	Leaf and Pod Spot				*Ascochyta Pisi*	
	Mildew		*Erysiphe Polygoni*			
	Foot Rot				*Ascochyta spp.* *Fusarium spp.*	
	Mosaic					Pea mosaic virus
	Marsh Spot					Manganese deficiency
Pear	Armillaria Root Rot			*Armillaria mellea*		
	Brown Rot		*Sclerotinia fructigena*			
	Blossom Wilt		*Sclerotinia laxa*			
Pine, Scots (and other conifers)	Armillaria Root Rot			*Armillaria mellea*		
Pine, White	Blister Rust			*Cronartium ribicola*		
Plum	Armillaria Root Rot			*Armillaria mellea*		
	Brown Rot		*Sclerotinia fructigena* and *S. laxa*			

	Blossom Wilt, Spur Blight and Wither Tip		*Sclerotinia laxa*		
	Silver Leaf			*Stereum purpureum*	
Potato	Common Scab				*Actinomyces spp.*
	Black Scurf and Stem Canker			*Corticium Solani*	
	Dry Rot				*Fusarium caeruleum*
	Blight	*Phytophthora infestans*			
	Powdery Scab	*Spongospora subterranea*			
	Wart Disease	*Synchytrium endobioticum*			
	Verticillium Wilt				*Verticillium albo-atrum*
	Leaf Roll				
	Mottle				
	Crinkle				
	Leaf Drop Streak				
	Rugose Mosaic				
	Net Necrosis				

Potato leaf roll virus
Potato virus X or A
Mixed infection of potato viruses X and A
Potato virus Y (primary symptoms)
Potato virus Y (secondary symptoms)
Mixed infection of potato leaf roll virus and potato virus A

HOST	COMMON NAME	PHYCOMYCETES	ASCOMYCETES	BASIDIOMYCETES	FUNGI IMPERFECTI	OTHER CAUSES OF DISEASE
Potato (cont.)	Tuber Blotch					Potato virus F
	Aucuba Mosaic					Potato virus G
Radish	Club Root	*Plasmodiophora Brassicae*				
Raspberry	Mildew		*Sphaerotheca Humuli*			
	Mosaic					Raspberry mosaic virus
Rye	Ergot		*Claviceps purpurea*			
	Mildew		*Erysiphe graminis*			
	Black Rust			*Puccinia graminis*		
	Brown Rust			*Puccinia dispersa*		
	Stripe Smut			*Urocystis occulta*		
Sainfoin	Mildew		*Erysiphe Polygoni*			
	Rot		*Sclerotinia Trifoliorum*			
Strawberry	Mildew		*Sphaerotheca Humuli*			
	Crinkle					Strawberry crinkle virus
	Yellow Edge					Strawberry yellow edge virus
Tobacco	Mosaic					Tobacco mosaic virus

Tomato	Grey Mould and Botrytis Fruit Spot	*Botrytis cinerea*
	Leaf Mould	*Cladosporium fulvum*
	Black Dot (" Root Rot ")	*Colletotrichum atramentarium*
	Fusarium Wilt	*Fusarium* spp.
	Foot Rot and Damping-off	*Phytophthora cryptogea*, *P. parasitica* and *Pythium* spp., esp. *P. ultimum*
	Blight	*Phytophthora infestans*
	Buckeye Rot	*Phytophthora parasitica*
	Black Root Rot	*Corticium solani*
	Verticillium Wilt	*Verticillium albo-atrum* and *V. Dahliae*
	Bacterial Canker	*Corynebacterium michiganense*
	Bushy Stunt	Tomato bushy stunt virus
	Spotted Wilt	Tomato spotted wilt virus
	Fern Leaf	Cucumber mosaic virus or strains of tobacco mosaic virus

HOST	COMMON NAME	PHYCOMYCETES	ASCOMYCETES	BASIDIOMYCETES	FUNGI IMPERFECTI	OTHER CAUSES OF DISEASE
Tomato (cont.)	Mosaic, Yellow Mosaic, Enation Mosaic and Streak					Various strains of tobacco mosaic virus
	Blossom-End Rot and Blossom Drop					Irregular water supply
	Dry Set					Imperfect pollination
	Blotchy Ripening					Usually incorrect balance of potash and nitrogen
	Green Back					Potash deficiency or exposure to high light intensities
Trefoil	Rot		*Sclerotinia Trifoliorum*			
Tulip	Fire				*Botrytis Tulipae*	
	Breaking					Tulip breaking virus
Turnip and Swede	Mildew		*Erysiphe Polygoni*			
	Dry Rot and Canker				*Phoma lingam*	
	Club Root	*Plasmodiophora Brassicae*				
	Mosaic					Turnip mosaic virus
	Brown Heart (Raan)					Boron deficiency

WALLFLOWER	Grey Mould				*Botrytis cinerea*	
	Club Root	*Plasmodiophora Brassicae*				
	Mosaic, and Flower Breaking					Cabbage ring-spot virus
WHEAT	Black Mould				*Cladosporium herbarum* and *Alternaria* spp.	
	Ergot		*Claviceps purpurea*			
	Mildew		*Erysiphe graminis*			
	Brown Foot Rot and Ear Blight				*Fusarium* spp. esp. *F. avenaceum* and *F. culmorum*	
	Take-all and Whiteheads		*Ophiobolus graminis*			
	Yellow Rust			*Puccinia glumarum*		
	Black Rust			*Puccinia graminis*		
	Brown Rust			*Puccinia triticina*		
	Bunt			*Tilletia caries*		
	Loose Smut			*Ustilago Tritici*		
	Eyespot				*Cercosporella herpotrichoides*	

Appendix II

List of Useful References

AINSWORTH, G. C. (1937). *The Plant Diseases of Great Britain—A Bibliography.* 273 pp. London, Chapman & Hall.

AINSWORTH, G. C., and BISBY, G. R. (1943). *A Dictionary of the Fungi*, 359 pp. Imperial Mycological Institute, Kew.

BAWDEN, F. C. (1943). *Plant Viruses and Virus Diseases*, 294 pp. Waltham, Mass., Chronica Botanica Co., London, Wm. Dawson.

BISBY, G. R. (1945). *An Introduction to the Taxonomy and Nomenclature of Fungi*, 117 pp. Imperial Mycological Institute, Kew.

British Mycological Society, Plant Pathology Committee (1944). *List of Common British Plant Diseases*, 61 pp., Cambridge, University Press.

BROOKS, F. T. (1928). *Plant Diseases*, 386 pp. Oxford, University Press.

GREEN, D. E. (1943). *Diseases of Vegetables*, 208 pp. London, Macmillan.

HALL, A. D. (1945). *The Soil*, 5th ed. London, Murray.

HEALD, F. D. (1933). *Manual of Plant Diseases*, 953 pp. New York, McGraw Hill.

LARGE, E. C. (1940). *The Advance of the Fungi*, 488 pp. London, Jonathan Cape.

LOWSON, J. M. (1945). *Textbook of Botany*, 584 pp. London, University Tutorial Press.

MARTIN, H. (1944). *The Scientific Principles of Plant Protection*, 385 pp. London, Edward Arnold.

Ministry of Agriculture and Fisheries Bulletins :

22 *Practical Soil Sterilization*, by W. F. Bewley.
23 *Edible and Poisonous Fungi.*
41 *Weeds of Grassland*, by H. C. Long.
77 *Tomatoes : Cultivation, Diseases and Pests*, by W. F. Bewley.
93 *Pests and Diseases of Sugar Beet*, by F. R. Petherbridge and H. H. Stirrup.
108 *Weeds of Arable Land*, by H. C. Long.
123 *Diseases of Vegetables*, by L. Ogilvie.
126 *Diseases of Crop Plants* (1933-42), by W. C. Moore.
129 *Cereal Diseases*, by W. C. Moore.

NELSON, A. (1946). *Principles of Agricultural Botany*, 556 pp. London and Edinburgh, Nelson.

SAMPSON, K., and WESTERN, J. H. (1941). *Diseases of British Grasses and Herbage Legumes*, 85 pp. Cambridge, University Press.

SMITH, G. (1946). *An Introduction to Industrial Mycology*, 271 pp. London, Edward Arnold.

SMITH, K. M. (1937). *A Textbook of Plant Virus Diseases*, 615 pp. London, Churchill.

SMITH, K. M. (1945). *Virus Diseases of Farm and Garden Crops*, 111 pp. Worcester, Littlebury & Co.

WALLACE, T. (1944). *The Diagnosis of Mineral Deficiencies in Plants* (including supplement), London, H.M. Stationery Office.

WESTON, W. A. R. DILLON (1948). *Diseases of Cereals*, 69 pp. London, Longmans Green.

WESTON, W. A. R. DILLON (1948). *Diseases of Potatoes, Sugar Beet and Legumes*, 86 pp. London, Longmans Green.

WHITEHEAD, T., MCINTOSH, T. P., and FINDLEY, W. M. (1945). *The Potato, in Health and Disease*, 400 pp. Edinburgh and London, Oliver & Boyd.

WORMALD, H. (1945). *Diseases of Fruit and Hops*, 294 pp. London, Crosby Lockwood.

Index

ABNORMAL germination of cereals, XXII
Actinomyces spp., 28
Aggressive infection—Chocolate Spot of beans, 31
Agricultural Improvement Council, 149
Air—composition of, 18, 20
American Gooseberry Mildew, LII, 114, 144, 145
Ammonification, 23
Anchusa spp., 112
Anguillulina dipsaci: on clover, 46, 79; on potato, 82
Aphanomyces spp., 71
Aphides: as fungus vectors, XI, 35; as virus vectors, I, 9, 130, 132-134, 136, 137, 139, 140; control of—by fumigation, 135
Aphis fabae as a virus vector, 136
Apple: Brown Rot, IX, 35, 38, 39; Mildew, 114; Scab, X, 35, 42
Armillaria mellea (Armillaria Root Rot), XLIII, 90, 91
Ascochyta Pisi, 70
Ascomycetes, 42
Atomaria linearis, XXXI, 72
Aucuba Mosaic: of potato, 131, 134; of tomato, 138
Authorities, 40

BACTERIA: and soil fertility, 24; denitrifying, 23; dispersal by rain, 103; early work on, 8; in soil, 22; nitrifying, 23; pathogenic to plants, 25, 103, 104
Bacterial canker of tomato, 25, 103, 104
Bacterium carotovorum on carrot, 25
——*radicicola*—see *Rhizobium leguminosarum*
—— *tumefaciens*, VI, 25
Barberry, LI, 108, 110; eradication of, 5, 109, 110, 146
Barger, G., 6
Barley, 54; Black Rust, 106; Brown Rust, 112; Covered Smut, XXV, 37, 53, 55, 60, 65; hot water treatment, 66; Leaf Blotch, XXII, 59; Leaf Stripe, XXII, XXVI, 30, 37, 55, 59, 65, 66, 68; Loose Smut,
Barley—*continued*
XXV, 37, 59, 60, 65, 66; Net Blotch, 67; phytocidal action of copper sulphate on, 52; potash deficiency, 123; Powdery Mildew, 39; pre-emergence blight, 66; proportion of seed treated in Britain, 61; soil in relation to, 13; Take-All and Whiteheads, 13, 77; treatment of seed—ancient remedies, 4; treatment with formaldehyde, 53; treatment with organo-mercury seed disinfectants, 55; Yellow Rust, 110, 111
Basidiomycetes, XVI, 42, 90, 108
Bawden, F. C., 10
Beans, 11; Chocolate Spot, III, 30, 31, 36, 70, 71; field, 70, 80; Mosaic, 137; nitrogen-fixing bacteria on, 23, (Fig.) 24; Rot, XXXVII, 13, 37, 38, 70, 71, 80; sclerotia in seed samples, 71; treatment with organo-mercury seed disinfectants, 71
Beaumont, A., 115
Beet: Blackleg, XXXI, 35, 37, 48, 71, 72; Crown Gall, VI; Downy Mildew, LVI, 48, 83, 118, 119; Downy Mildew—similarity of symptoms with Heart and Dry Rot, 127; eelworm (" Sickness "), XXXVIII, 13, 80-83, 145; effect of chalk on, IV; Heart and Dry Rot (boron deficiency), LVII, 27, 48, 126, 127; Leaf Spot, XIII, 41; Mosaic, 135, 136; nitrogen deficiency, 122; phosphorus deficiency, 122; Pigmy Mangold Beetle, XXXI, 72; Speckled Yellows (manganese deficiency), LVII, 27, 125; Stringy Root, 47, 72; treatment with organo-mercury seed disinfectants, 72; Violet Root Rot, XXXV, 78; virus diseases, 135-137; Yellows, Frontispiece, 136
Berberis vulgaris—see Barberry
Berkeley, M. J., 7
Bewley, W. F., 95
Biffen, R. H., 14

Binomial nomenclature, 38
Black Dot of tomato, 48, 96-98, (Fig.) 97, 100
Blackcurrant, 146
Blackleg of beet, XXXI, 35, 37, 48, 71, 72
Black Ringspot of *Cruciferae*, 137
Black Rust (see also *Puccinia graminis*): epidemics, 34; in North America, 34; of barley, 106; of cereals, 39, 106; of grasses, 106; of oats, 106; of rye, 106; of wheat, XLVIII, XLIX, L, LI, 106-110
Black Scurf—see Potato
Blight, of potato—see Potato Blight; of tomato—see Tomato
Blossom Drop of tomato, 105
Blossom End Rot of tomato, 105
Blotchy Ripening of tomato, 105
Bluestone—see Copper sulphate
Booer, J. R., 56
Borax, 27, 48, 127
Bordeaux mixture: for the control of Celery Leaf Spot, 76; for the control of Potato Blight, 116, 117
Boron: and plant nutrition, 26, 27, 44, 120, 126, 127; deficiency, LVII, 27, 48, 126, 127; toxicity due to excess of, 128
Botrytis spp., 28; aggressive infection, 31; dispersal of spores, 36; non-aggressive infection, 30; on beans, III, 30, 31, 36, 70
—— *cinerea*, 103; on beans, 70; on tomato, XLVI, 102
—— *Fabae*, 70
—— Fruit Spot—see Tomato
—— *infestans*, 40
——*Tulipae*, XVIII, 49
Brassicae: Canker (Dry Rot), 73—see also Turnip; Club Root, 42—see also *Plasmodiophora Brassicae;* Powdery Mildew, 114; treatment with organo-mercury seed disinfectants, 73; virus diseases, 137
" Break " : of tulip, Frontispiece, 129; of other ornamentals, 137
Brevicoryne brassicae, 137
British Mycological Society, 45, 46
Broccoli, 126, 137
Broom Rape, II
Brown Foot Rot and Ear Blight of wheat, 47
Brown Heart (Raan) of turnip and swede, 126, 127
Brown Rot: of apple, IX, 35, 38, 39; of cherry, 39; of plum, 39
Brown Rust of cereals, 112; effect of lithium on, 121
Buck-Eye Rot of Tomato, 96
Buddin, W., 95
Buller, A. H. R., 33, 37
Bunt (Covered Smut) of wheat, XXIII, 37, 52, 60, 63, 69; control measures, 53, 54, 64; number of spores in Bunt ball, 37
Bushy Stunt of tomato, II, 10

Cabbage: Club Root, XL, 84-86; iron deficiency, 125; nitrogen deficiency, 122; Stem Flea Beetle, 73; virus diseases, 137 (see also *Brassicae*)
Calcium: and soil acidity, 26, 124; in plant nutrition, 44, 120, 123 (see also Lime)
Cambridge University Farm, 54, 55
Canadian Water Weed, 141
Canker: of *Brassicae*, 73; of turnip and swede, 35, 37, 73 (see also Dry Rot)
Carbohydrates, 11, 21, 22
Carbon: in the nutrition of fungi, 29; in plant nutrition, 25
Carbon assimilation—see Photosynthesis
Carbon dioxide: in plant metabolism, 21, 27; in respiration, 19-22; in the air, 18, 21
Carleton, M. A., 39
Carrot: Broom Rape on, II; Soft Rot, 25; Violet Root Rot, XXXV, 78; Wild, V, 15
Cauliflower: Hollow Stem or Browning, 126; Mosaic, 137
Cavendish, H., 19
Celery, 74; Cracked Stem, 126; Fly, 74; Leaf Spot (Blight), XXXII, XXXIII, 35, 37, 74-76; Leaf Spot—control measures, 76; Leaf Spot—effect of lithium on, 121
Cephus pygmaeus, 47
Ceratostomella Ulmi, 144
Cercospora beticola, XIII, 41
Cercosporella herpotrichoides on wheat, XVII, 47
Cereals—see under individual crops
Cherry—Brown Rot, 39
Cheshunt Compound, 95, 96
——Experimental and Research Station, 102
Chestnut Blight, 144
" Chili saltpetre," 18
Chlorine—in plant nutrition, 121
Chlorophyll, 21
Chocolate Spot—see Beans
Chytridiales, 84
Cladosporium fulvum, 40, 104
—— *herbarum*, 113

Claviceps purpurea: on cereals, XI, 39, 40; on grasses, 39, 41; on rye, 5, 6, 35; physiologic races, 39
Clover: Mosaic, 137; nitrogen-fixing bacteria on, 23; potash deficiency, 123; reaction to *Sclerotinia Trifoliorum*, 80; Rot, XXXVI, 13, 37, 38, 40, 42, 46, 79; Sickness, 79; Stem Eelworm, 46, 79; strains, 14, 38; strains—susceptible to Clover Rot, 79
Club Root—see *Plasmodiophora Brassicae*
Colletotrichum spp., 42
—— *atramentarium*, 48, 96, (Fig.) 97, 97
Colorado Beetle, 142, 144
Contagious Diseases (Animals) Act, 1869, 142
Copper: in the nutrition of fungi, 29; in plant nutrition, 26, 44, 120
—— carbonate—as a seed disinfectant, 53, 54
—— sulphate: phytocidal action, 52, 65, 66; use as a seed disinfectant, 52, 53, 64
Correns, C., 13
Corticium Solani: on potato, XIV, 42, 124; on tomato, 93, 94, 96
Corynebacterium michiganense, 25, 103, 104
Covered Smut: of barley, XXV, 37, 53, 55, 60, 65; of oats, 37, 53, 55, 67; of wheat—see Bunt
Cracked Stem—see Celery
Craigie, J. H., 32, 39, 107, 108
Cranesbills, V, 15
Cresylic acid, 92, 102
Crinkle: of potato, 131, 134; of strawberry, 140
Cronartium ribicola, 144
Crookes, W., 19
Crown Gall, VI, 25
Crown Rust of oats, 112
Cruciferae: Beet Eelworm on, 81; Black Ringspot virus, 137
Cucumber Mosaic, 140
Cuprous oxide as a fungicide, 95

Dahlia—Cucumber Mosaic on, 140
Damping-off: of peas, 70; of tomato, 93-95
Darnell Smith, G. P., 53
Darwin, Charles, 12
De Bary, A., 40
Deficiency diseases, LVII, 26, 27, 120-128
Deficiency: of boron, LVII, 27, 126-128; of calcium, IV, 123, 124; of iron, 124, 125; of magnesium, 27, 124, 125; of manganese, LVII, 27, 125, 126, 128; of phosphorus, 122; of potassium, 123
Denitrification, 23
Department of Agriculture for Scotland, Plant Pathology Laboratory, 151
De Saussure, T., 21
Destructive Insects and Pests Acts, 87, 142, 143
De Vries, H., 12, 13
Didymella Lycopersici, XLIV, XLV, 100-102
Docks, V, 15
Dominion Laboratory of Plant Pathology, Winnipeg, 32, 107
Dominion Rust Research Laboratory, Winnipeg, 32, 39
Downy Mildew: comparison with Powdery Mildew, 112, 118; o onion, 118; of beet, LVI, 48, 83, 118, 119, 127
Dry Rot: of potato, XLII, 88, 89; of turnip, 72, 73
Dry Set of tomato, XLVII, 105
Dutch Elm Disease, 144

Ear Blight of wheat, 47
East Malling Research Station, 27
Eelworm: control by hot-water treatment, 61; on beet, XXXVIII, 13, 80-83, 145; on clover, 46, 79; on potato, XXXIX, 81-83; other hosts, 81
Elodea Canadensis, 141
Endothia parasitica, 144
Engledow, F. L., 14
Epidemics: influence of weather on, 50, 114-116; of Black Rust, 34; of Potato Blight, 35, 114-116; rôle of asexual spores in, 31, 34, 35, 115
Ergot—see *Claviceps purpurea*
Ergotism, 5, 6
Eriksson, J., 39, 40
Erysiphaceae, 112
Erysiphe graminis, VIII, 39, 112, 113, 121, 122
—— *Polygoni*, 114
Esdorn, I., 56
Eyespot of wheat, XVII, 47

Fern Leaf of tomato, 140
Fertilizers: nitrogenous, 18, 26, 139; phosphatic, 26; potassic, 26, 139
Finger and Toe—see *Plasmodiophora Brassicae*
" Fire " of tulip, XVIII, 49, 50
Fischer, E., 22
Foot Rot of tomato, 93-95, (Fig.) 94
Formaldehyde, 53, 66, 89, 92, 95, 102; as a seed disinfectant, 53, 64-67, 69, 75; use in soil sterilization, 92 95, 102, 138

Formalin—see Formaldehyde
Frazer, J. G., 2
Frit Fly, 54
Fruit Rot of tomato, XLV, 100-102
Fruit tree nutrition, 27
Fumigation, 139; with nicotine, 135; with sulphur, 101, 104
Fungi: basis of classification, 28, 31, 41-43; common names, 45, 153-163; conditions required for spore germination, 33-35, 85, 95, 107; number of spores produced by, 33, 37; nutrition of, 28, 29; phases in life cycle, 31, 41, 87, 89, 107-114; physiology of parasitism, 30; scientific names, 38, 40, 41; sexuality, 109; spore dispersal, XII, 33, 35, 36, 64, 101, 106, 109, 115; spore sizes, 31; spores in the air, 34, 106-119; spores in the soil, 37, 84-92, 95, 96, 98, 101; synthetic media for, 29
Fungi Imperfecti, 42, 88
Fusarium spp., 42, 89; in the soil, 70, 88, 89; on peas, 70; on tomato, 48, 100
—— *avenaceum:* on potato, 89; on wheat, 47
—— *caeruleum*, XLII, 88, 89
—— *culmorum*, 47
Fusarium Wilt of tomato, 48, 100

Gall Weevil, 86
Gassner, G., 56
Germ Theory of Disease, 8
Germination: of cereal seed, XXII; of fungus spores, 33-35, 85, 95, 107
Geuther, T., 53
Gooseberry: Armillaria Root Rot, XLIII; Mildew, LII, 114, 144, 145
Grand Rapids Disease of tomato, 103—see also *Corynebacterium michiganense*
Grasses: Black Rust, 106; Powdery Mildew, 39, 112; Take-All, 47, 77, 78, 83; Yellow Rust, 110
Green Back of tomato, 105
Greenfly—see *Aphides*
Grey Leaf of oats, 45, 125
Grey Mould—see *Botrytis*
Growth-promoting substances, 5, 29, 61

Heart and Dry Rot of beet, LVII, 27, 48, 126, 127
Helicobasidium purpureum, XXXV, 78
Helminthosporium spp., 30
—— *Avenae*, XXVII, 54, 67
—— *gramineum*, XXII, XXVI, 66
—— *teres*, 67
Hellriegel, 23
Hemiptera, 130
Heterodera rostochiensis, XXXIX, 82
—— *schachtii*, XXXVIII, 80, 82
Hoffman, A. W. von, 53
Honey Agaric—see *Armillaria mellea*
Hop Mildew, 114
Hormones, 5, 29, 61
Hot-water treatment, 60, 61; against eelworm, 61; against Loose Smut of barley, 66; against Loose Smut of wheat, 61, 64, 65

Ingenhousz, J., 21
Insects: as fungus vectors, XI, 35; as virus vectors, I, 9, 130, 132-137, 139,140
International Phytopathological Conference, 1914, 146
International Rules of Botanical Nomenclature, 46
Iron: deficiency of, 124, 125; in the nutrition of fungi, 29; in plant nutrition, 26, 44, 120, 124
Iwanowski, D., 9, 130

Jassidae, 130
"Jaunisse"—see Beet Yellows
Jensen, J. L., 60, 61
Johannsen, W., 14

Kale: nitrogen deficiency, 122; Powdery Mildew, 114
Kent, N. L., 121
Kircher, A., 6
Koch, R., 8
Kühn, J., 52

Lamarck, J. B. de, 12
Large, E. C., 5
Leaf and Pod Spot of pea, 70
Leaf Blotch of barley, XXII, 59
Leaf Curl of raspberry, 140
Leaf Drop Streak of potato, 131, 133
Leaf Hoppers, 130
Leaf Mould—see Tomato
Leaf Roll of potato, Frontispiece, 9, 131, 133
Leaf Spot: of beet, XIII, 41; of celery, XXXII, XXXIII, 35, 37, 74-76, 121; of oats, XXVII, 37, 54, 55, 67, 68, 126
Leaf Stripe: of barley, XXII, XXVI, 59, 65-68; of oats—see Leaf Spot
Leeuwenhoek, A. van, 6
Legumes, virus disease, 137
Leguminosae, 23
Leptinotarsa decemlineata, 142, 144
Lettuce Mosaic, 140
Lime: and soil acidity, IV, 26, 45, 47, 124; in the control of *Plasmodiophora Brassicae*, 85

Linnaeus (Carl von Linné), 38
Lister, J., 8
Lithium, 121
Lodging, XVII, 14, 47
Long Ashton Research Station, 27, 70, 121
Loose Smut: of barley, XXV, 37, 59, 60, 64-66; of oats, 37, 67; of wheat, XXIV, 37, 59-61, 64-66
Lucerne: Mosaic, 137; nitrogen-fixing bacteria on, 23; reaction to *Sclerotinia Trifoliorum*, 80
Lupin: Mosaic, 137; nitrogen-fixing bacteria on, 23
Luthra, J. C., 60

Magnesium: in the nutrition of fungi, 29; in plant nutrition, 25, 44, 120, 124, 125
Maize, 2
Major elements in plant nutrition, 25, 26, 44, 120-124
Manganese: deficiency of, 27, 45; in plant nutrition, 26, 44, 120, 125; sulphate, 27, 126
Mangold—see Beet
Marrow—Cucumber Mosaic on, 140
Martin, H., 57
Massachusetts—legislation for the destruction of Barberry, 5, 146
Mealy Cabbage Aphis, 137
Mendel, G. J., 12, 14, 32
Mild Mosaic of potato—see Potato
Mildew, 59; Downy, LVI, 48, 83, 112, 118, 119, 127; Powdery, VIII, 30, 39, 112-114, 118, 121, 122
Ministry of Agriculture and Fisheries: Approval Scheme for Insecticides and Fungicides, (Fig.) 57, 58, 146, 147; history of, 142; husbandry experimental farms and horticultural stations, 151; National Agricultural Advisory Service, LIX, 149, 150; Plant Pathology Laboratory, 145; Provincial Advisory Service, 149
Minor elements—see Trace elements
Molybdenum in plant nutrition, 26, 44, 120
Montagne, C., 40
Mosaic: of beet, 135, 136; of cauliflower, 137; of cucumber, 140; of legumes, 137; of lettuce, 140; of potato, 9, 133—see also Potato; of tobacco, 9, 10, 130, 140; of tomato, 10, 130, 137-139
Mottle (Mild Mosaic) of potato, 131, 134
Mustard, 11
Mutation Theory, 12
Myxomycetes, 42, 43, 84
Myzus persicae as a virus vector, 9, 132, 135-137

National Institute of Agricultural Botany, Cambridge, LX, 15
Net Blotch of barley, 67
Net Necrosis of potato, 131, 133
Nicotine as a fumigant, 135
Nitrates: in the nutrition of fungi, 29; in plant nutrition, 44
Nitrate of soda, 18
Nitrobacter, 23
Nitrification, 23
Nitrogen: cycle, 25; fixation, 23; from the soil, 22; in excess, 30; in the nutrition of fungi, 29; in plant nutrition, 18, 25, 26, 44, 120, 121; in the air, 18
Nitrogenous fertilizers, production from atmospheric nitrogen, 19
Nitrosococcus, 23
Nitrosomonas, 23
Nodules on leguminous roots, 23, (Fig.) 24

Oats, 67; Black Rust, 106; Covered Smut, 37, 53, 55, 67; Crown Rust, 112; Frit Fly, 54; Grey Leaf (manganese deficiency), 45, 125; Leaf Spot, XXVII, 30, 37, 54, 55, 67, 68, 126; Loose Smut, 37, 67; phytocidal action of copper sulphate on, 53, 55; Powdery Mildew, 39; pre-emergence (seedling) blight, XXVII, 55, 67, 68; proportion of seed treated in Britain, 61; Smuts, XXIV, 37, 53, 55, 60, 61; treatment with seed disinfectants, XXVIII, 53, 55, 69
O'Brien, G., 55
Official Seed Testing Stations, LX, 16, (Fig.) 17, 74, 75, 148, 151
Onion—Downy Mildew, 118
Ophiobolus graminis, 59; on barley, 47, 77; on grasses, 47, 77, 78, 83; on wheat, XXXIV, 47, 77
Opuntia vulgaris, 141
Organo-mercury seed disinfectants, XXVIII, 55, 58, 64, 65, 67, 70-73, 89; approved proprietary products, 57; care in handling, 59; composition of, 56; early development in, 56; phytocidal action of, 59
Origin of Species, 12
Orobanche sp.—on carrot, 11
Ornithogalum umbellatum, 112
Oscinella frit, 54
Oxygen, in the nutrition of fungi, 29; in the air, 18, 21, 22

Pasteur, L., 8
Peas: Damping-off, 69, 70; Leaf and Pod Spot, 70; Marsh Spot (manganese deficiency), 126; Mosaic, 137; nitrogen-fixing bacteria on, 23; Powdery Mildew, 114; reaction to *Sclerotinia Trifoliorum*, 80; treatment with seed disinfectants, XXX, 70
Penicillium spp.—in blue-veined cheese, 28
—— *notatum*, X, 28
Peronospora spp., LVI
—— *destructor*, 118
—— *Schachtii*, LVI, 48, 118, 127
Peronosporales, 118
Persoon, C. H., 40
Peters, M., 3, 61
Phoma apiicola, 75
—— *Betae*, XXXI, 48, 71
—— *lingam*, 72, 73
Phosphorus, 128; deficiency of, 44; in the nutrition of fungi, 29; in plant nutrition, 25, 26, 44, 120, 122
Photosynthesis, 21, 22
Phycomycetes, 41, 42, 84, 112
Phylloxera on vines, 146
Physiologic disorders of tomato, XLVII, 105
Physiologic races, 32; differential hosts, 39; hybridization, 109; of *Cladosporium fulvum*, 40; of *Claviceps purpurea*, 39; of *Erysiphe graminis*, 39, 112; of *Erysiphe Polygoni*, 114; of *Phytophthora infestans*, 40, 118; of *Puccinia glumarum*, 39, 110, 111; of *Puccinia graminis*, 39, 109; of *Sclerotinia laxa*, 39; segregation, 40; varietal resistance to, 39, 109, 111, 112
Physiologic varieties of *Puccinia graminis*, 39, 106
Phytophthora spp., 94, 95
—— *cryptogea*, 93, 94
—— *infestans:* I, LIII, 7, 40, 42, 114-118; on tomato, XLVII, 104, 105
—— *parasitica*, 93, 94, 96
Pigmy Mangold Beetle, XXXI, 72
Pirie, N. W., 10
Plant analysis, 25, 121, 128
Plant Breeding Institute, Cambridge, 14
Plants: influence of environment on susceptibility to disease, 45, 47, 49; nutrition of, 22-27, 44, 120-128; respiration in, 20, 22
Plasmodiophora Brassicae, XL, 26, 42, 84-86, 128
Plum—Brown Rot, 39
Podosphaera leucotricha, 114
Potassium, 128; in the nutrition of fungi, 29; in plant nutrition, 25, 26, 44, 120, 123
Potato, LV, 90, 94, 130; Aucuba Mosaic, 131, 134; Black Scurf and Stem Canker, XIV, 42, 124; Blight—see Potato Blight; calcium deficiency, 123; certification, 134, 135, 146; Crinkle, 131, 134; Dry Rot, XLII, 88, 89; Eelworm, XXXIX, 81-83; Leaf Drop Streak, 131, 133; Leaf Roll, Frontispiece, 9, 131-133; Mosaic, 9, 133; Mottle (Mild Mosaic), 131, 134; Net Necrosis, 131, 133; phosphorus deficiency, 122; potash deficiency, 123; Powdery Scab, XV, 42; Root Eelworm, XXXIX, 82, 83; Rugose Mosaic, 131, 133; Sickness, XXXIX, 13, 82, 83; spraying, LIV, 116, 117; Stem Canker, XIV, 42, 124; Stem Eelworm, 82; treatment of the tubers, 89; Tuber Blotch, 131; Violet Root Rot, 78; virus A, 134; virus diseases, Frontispiece, 9, 50, 83, 131-135; virus X, 134; Wart Disease, XLI, 42, 86-88, 144, 146
Potato Blight, I, LIII, LIV, 40, 42, 83, 105, 116, 117; control measures, 116-118; epidemic spread, 7, 35, 114-116; geographical distribution, 7, 114-116; importance of hygiene, 50, 117-118; in tubers, 50, 117; influence of weather, 35, 114-116; mode of infection, 35, 50, 115, 116; on tomato, XLVII, 104, 105; physiologic races, 40, 118; protective spraying against, LIV, 116, 117; symptoms, 82, 114, 115; varieties resistant to, 40, 118
Powdery Mildew, VIII, 30, 113; comparison with Downy Mildew, 112, 118; of apple, 114; of *Brassicae*, 114; of cereals, 39, 112, 121, 122; of grasses, 39, 112; of hops, 114; of peas, 114
Powdery Scab—see Potato
Pre-emergence (seedling) Blight, XXVII, 55, 66-69
Prentice, E. G., 55
Prévost, B., 6, 52
Prickly Pear, 141
Pseudomonas radicicola, 23, (Fig.) 24
Psylliodes chrysocephala, 73
Puccinia spp., 28
—— *anomala*, 112
—— *coronata*, 112
—— *dispersa*, 112

Puccinia—continued
—— *glumarum*, 41, 106; host range, 39, 110; phases in life cycle, 110, 111; physiologic races, 39, 110, 111; varieties of wheat resistant to, 111
—— *graminis*, 106; control measures, 109, 110; geographical distribution, 32, 106, 108, 110; host range, 39, 106; losses due to, 32; on wheat, XLVIII, XLIX, L, LI, 32, 34, 40, 106-110, 146; phases in life cycle, 107, 108; physiologic races, 32, 109; physiologic varieties, 39, 106; resistance to, 32, 109
—— *triticina*, 112, 121
Pyrenophora Avenae, XXVII, 54, 67, 126
—— *graminea*, XXII, XXVI, 66
—— *teres*, 67
Pythium spp., 48, 70, 71, 94
—— *ultimum*, 93

RAAN—see Turnip
Raspberry Leaf Curl, 140
Red beet—see Beet
Respiration, 11, 19, 20, 22
Reversion of blackcurrant, 146
Rhamnus spp., 112
Rhizobium leguminosarum, 23, (Fig.) 24
Rhizoctonia, spp., 42, 71—see also *Corticium Solani*
Rhynchosporium Secalis, XXII, 59
Riehm, E., 56
Rivers, T. M., 9
Root Eelworm of potato, XXXIX, 82, 83
Root Rot: of celery, 75; of tomato—see Black Dot
Rothamsted Experimental Station, 27
Rugose Mosaic of potato, 131, 133
Rust, 2, 5, 28, 29, 42, 59, 106
Rye: Black Rust, 106; Brown Rust, 112; Ergot, 5, 6, 35; Powdery Mildew, 39; Smuts, 61; Stripe Smut, XXIX, 68; treatment with copper sulphate, 53; Yellow Rust, 110

SACCARDO, P. A., 41
Sachs, J. von, 21
Sainfoin: nitrogen-fixing bacteria on, 23; reaction to *Sclerotinia Trifoliorum*, 80
Sale of Diseased Plants Orders, 145
Sale of Strawberry Plants and Blackcurrant Bushes Order, 1946, 146
Scab of apple, X, XI, 35, 42
Schulthuss, H. H., 52
Sclerotinia Disease of bean—see Beans
Sclerotinia fructigena, IX, 38, 39
—— *laxa*, 39
Sclerotinia—continued
—— *Trifoliorum:* on beans, XXXVII, 13, 37, 38, 70, 71, 80; on clover, XXXVI, 13, 37, 38, 40, 42, 46, 79; on other hosts, 80; on synthetic media, VII
Seed: contamination, 37, 65, 67, 68; diseases carried by, 37, 52-76; disinfectants, XXVIII, 52-58, 64-67, 69-73, 75, 76, 89; disinfection, XIX, 37, 52, 72; freedom from disease, 76; germination, XXII, 11, 15, 63, 70; hot-water treatment, 60, 61, 64-66; infection of, 37, 60, 64, 66, 67, 74, 75; machines for treatment of, XIX, XX, XXI, 54, 56, 58; proportion treated in Britain, 61; protectants, 11, 69, 76; steeps, 3-5, 52; treatment on barn floor, XX, 52, 58
Seedling Blight, 69; of barley, 66; of oats, 55, 67, 68
Seeds: sclerotia as impurities in, 71; weeds as impurities in, V, 15, 63
Seeds Act, 1920, V, 15, 147, 148
Senebier, J., 21
Septoria spp., 42, 74
—— *Apii*, 74
—— *Apii-graveolentis*, XXXII, XXXIII, 74, 121
Sheep's Sorrel, 26
Silicon, 121
Silver Leaf, 50
Sleepy Disease—see Tomato, Verticillium Wilt
Smut, 2-6, 42, 52
Smuts: of oats, XXIV, 37, 53, 55, 60, 61; of rye, 61
Sodium, 121
Soft Brome grass, V, 15
Soft Rot of carrot, 25
Soil: analysis, 128; formation, 27; *Fusarium* spp. in, 47, 70, 88, 89; influence on plant growth, 13, 14, 45, 70, 72; liming to control acidity, IV, 26, 45, 47, 124; "sickness," 13, 77-83; sterilization, 78, 91, 92, 95, 102, 104, 138
Soil-borne fungi, 84-103
Solanaceae, 139
Sorrels, V, 15
Species Plantarum, 38
Speckled Yellows—see Beet
Speed, A., 3
Sphaerotheca Humuli, 114
—— *mors-uvae*, LII, 114, 144
Spongospora subterranea, XV, 42
Spotted Wilt of tomato, Frontispiece, 139, 140

Spraying, LIV, 116, 117, 126
Spurrey, 26, 47
Stakman, E. C., 32, 39
Stanley, W. M., 9
Stapledon, R. G., 14
Stem and Fruit Rot of tomato, XLIV, XLV, 100-102
Stem Canker—see potato
Stem Eelworm: on clover, 46, 79; on potato, 82
Stereum purpureum, 50
Stinking Smut—see Bunt
Strawberry, 90; certification, 146; Crinkle, 140; Yellow Edge, 140
Streak of tomato, 139
Stringy Root—see Beet
Stripe Smut of rye, XXIX, 68
Sugar beet—see Beet
Sugar Beet Eelworm Order, 145
Sulphur: as a fumigant, 101, 104; dusting against Black Rust, LII, 110; in the nutrition of fungi, 29; in plant nutrition, 25, 44, 120
Sun Scald of tomato, 105
Swede varieties resistant to *Plasmodiophora Brassicae*, 85—see also Turnip
Sylloge Fungorum Omnium Hucusque Cognitorum, 41
Synchytrium endobioticum, XLI, 42, 86, 87; geographical distribution, 86, 87; immune and susceptible varieties, 88; legislation, 144, 146

Take All and Whiteheads—see *Ophiobolus graminis*
Technical Instruction Act, 1889, 149
Thalictrum sp., 112
Thielaviopsis basicola, 100
Thrips as virus vectors, 130, 139
Thymol-kaolin dust, 89
Tillet, M., 6, 52
Tilletia caries, XXIII, 63—see also Bunt
Tobacco Mosaic, 9, 10, 130; on tomato, 140
Tomato, 48, 93-105; Bacterial Canker, 25, 103, 104; Black Dot (Root Rot), 48, 96-98, (Fig.) 97, 100; Blight, XLVII, 104, 105; Blossom Drop, 105; Blossom End Rot, 105; Blotchy Ripening, 105; Botrytis Fruit Spot, XLVI, 103; Buck-Eye Rot, 96; Bushy Stunt, II, 10; Damping-Off and Foot Rot, 93-95, (Fig.) 94; Dry Set, XLVII, 105; Fern Leaf, 140; Fusarium Wilt, 100; Green Back, 105; Grey Mould, XLVI, 102; Leaf Mould, 40, 104; magnesium deficiency, 124; mixed virus streak, 139;
Tomato—*continued*
Mosaic, 10, 130, 137, 138; physiological disorders, 105; seedling diseases, 93-96; Spotted Wilt, Frontispiece, 139, 140; Stem and Fruit Rot, XLIV, XLV, 100-102; Streak, 139; Sun Scald, 105; Verticillium Wilt, XLIV, 48, 50, 95, 98-100, (Fig.) 99; virus diseases, 137-140; Wire Stem, 96
Trace elements: in the nutrition of fungi, 29; in plant nutrition, 25-27, 44, 45, 48, 120, 121, 124-127; toxicity due to excess, 27, 128
Treatment of seed—see Seed
Trefoil: nitrogen-fixing bacteria on, 23; reaction to *Sclerotinia Trifoliorum*, 80
Tschermak, E. von, 13
Tuber Blotch of potato, 131
Tubeuf, K. F. von, 53
Tulip: "Break," Frontispiece, 129; Fire, XVIII, 49, 50
Tull, J., 2
Turnip, 13, 72; Brown Heart (Raan), 126, 127; Canker and Dry Rot, 35, 37, 72, 73; Club Root, 26, 85; Powdery Mildew, 114; varietal resistance to *Plasmodiophora Brassicae*, 85

University of Reading, 73
Urocystis occulta, XXIX, 68
Ustilago spp. on oats, XXIV—see also Oats, smuts
Ustilago Avenae, 67—see also Oats, Loose Smut
—— *Hordei*, XXV, 65—see also Barley, Covered Smut
—— *Kolleri*, 67—see also Oats, Covered Smut
—— *nuda*, XXV, 65—see also Barley, Loose Smut
—— *Tritici*, XXIV, 64—see also Wheat, Loose Smut

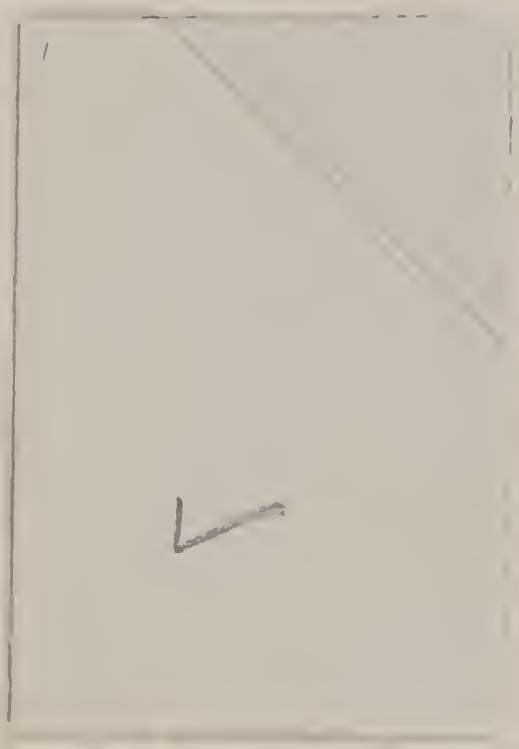
Vectors, I, XI, 9, 35, 130, 132-137, 139, 140
Venturia inaequalis, X, XI, 42
Verticillium albo-atrum, XLIV, 98-100, (Fig.) 99—see also Tomato, Verticillium Wilt
—— *Dahliae*, 100
Verticillium Wilt of tomato—see Tomato
Vetches: nitrogen-fixing bacteria on, 22, 23; reaction to *Sclerotinia Trifoliorum*, 80
Vines, *Phylloxera* on, 146
Violet Root Rot, XXXV, 78

Virus: first discovery of, 9; nature of, II, 9, 10, 130; transmission of, I, 9, 130, 132-137, 139, 140
Virus diseases, Frontispiece, 129-140, 146
Virus Yellows—see Beet

Wallace, T., 121
Wart Disease—see *Synchytrium endobioticum*
Wart Disease Orders, 144, 146
Weather: and Beet Black Leg, 71; and Black Rust, 34, 109, 110; and Clover Rot, 79; and Celery Leaf Spot, 75; and epidemics, 35, 50; and plant growth, 45; and Potato Blight, 35, 114-116; and spread of spores by wind and rain, 35, 36, 64, 75, 101, 106, 109, 115
Weeds scheduled under the Seeds Act, 1920, V, 15
Weston, W. A. R. D., 56
Wheat, LII, 2, 4, 13, 14, 46, 113; Black Rust, XLVIII, XLIX, L, LI, 32, 34, 40, 106-110, 146; Brown Foot Rot and Ear Blight, 47; Brown Rust, 112, 121; Bunt (Covered Smut), XXIII, 37, 52-55, 60, 63, 69; *Cladosporium herbarum* on, 113; Eyespot, XVII, 47; frost injury, III; hot-water treatment, 60, 61, 64, 65; lodging, XVII, 47; Loose Smut, XXIV, 37, 59-61, 64, 66; Powdery Mildew, 39, 121, 122; proportion of seed treated in Britain, 61; Smut, 4, 6, 52; Stinking Smut, 63—see also Bunt; Take All and Whiteheads, XXXIV, 13, 37, 47, 77; treatment of seed with chemicals, XIX, 52-55, 59-61, 64, 65; varieties resistant to Yellow Rust, 111; varieties susceptible to Loose Smut, 60; Yellow Rust, 110, 111
Whiteheads—see *Ophiobolus graminis*
White Pine Blister Rust, 144
Wilfarth, 23
Wire Stem of tomato, 96

Yellow Edge of strawberry, 140
Yellow Rust, 14, 41, 106; host range, 39, 110; physiologic races, 39, 111
Yorkshire Fog, V, 15

Zinc: in the nutrition of fungi, 29; in plant nutrition, 26, 44, 120

Made and Printed in Great Britain by The Garden City Press Limited
at Letchworth, Hertfordshire

CHECKED
CHECKED 2008
VERIFIED 2013
SV2019